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Hydrological adaptation for a 1D Hydromorphological Model

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Summary

Introduction:

The morphodynamic development of a river is a theme of great interest. In the last century the river were generally deep modified and exploited for different human needs. The main aim of the modification and the construction along the river course were the protection of the village, built in the near of the river, and the development of agricultural and industrial activities, for example the production of electric power. For this reasons, the water flow within the river changed in the meaning of discharge and above all in the grain size distribution. Often, the measures that interested the river, for example dam, gate and weir used for electric power station or for control the river behavior, prevent the sediment in their natural flow change. River morphology change usually require long period and are also dependent on the river bed formative flood discharges. The effects of river engineering measures between adjacent sections are recognizable in some cases after many years or decades. An essential prerequisite for assessing the effects and modification in the area of the river is to analyze and compare profile data from previous years and decades. A situation from an earlier period, for example after the construction and operation of hydroelectric power station in the area object of examination, has an influence on the morphology of the river, and can be used as a reference starting point. The morphology is naturally determined almost exclusively by the so called bed flow. Only the intersection and overlapping of the information from the profile data with the long-term level data allows an overall understanding of river dynamics of the considered river section. Distortion of sediment transportation flow can originate new erosion or deposition that can damage the previous river engineer measurement. For those reasons, in the last years, many studies focused on physical alteration of the river bed, the river flow regime and the bed load transport in relation with engineer measures on the river itself. Once understood the consequences of the modification, a new river plan could be made for its management.

Before the progression of computer system it was possible only two kind of study: physical model and study on the field. The problem that present the study on the fields are multiple and the most important concern the boundary condition: is difficult to know at the time of the measurement all the exactly information about the study case. The physical model (Papanicolaou, 2008) are delicate because of the distortion effects: if Freude and Reynolds number do not respect the right scale model the results lose their veracity. Furthermore when is necessary a study of different problem in a big area, the physical model need for each case a specific geometry to focus on the singular solution. The economical aspect, and the time needed to reproduce the experiment are also relevant. Nowadays the physical model are used only in specific case, for example in the area of the river where the flows vary rapidly because of an obstacle like a bridge pile interacting with the flow. In some case, physical models are associate to computational model to understand and investigate a particular process belonging to a broad investigation. (Papanicolaou, 2008)

Thanks to the development of computer system of the last years, computational models have been improved and they can reproduce a wide range of problem referred to different real situation reducing the effort in term of time, reproducibility and money that a real investigation in the field or a physical model can give. Morphological problem can be studied in one, two or three dimension depending on the difficulty of the geometry of the area object of study. The number of equation to solve in 2D and 3D models can produce a big effort in term of computation and resolution, so it is important to assign to a specific problem the right dimension model to get results in a simpler way.

Thanks to the area object of study without geometry or situation that require 2D or 3D investigation, this work considers the advancement of a one dimensional morphodynamic model describing the evolution of the lower part of river Iller, an affluent of the Danube. It will be exploited the software system *BASEMENT*, a specific program that gives the possibility of computation of one and two dimensional flows with moving boundaries and appropriate models for bed load as well as suspended load and also allows a morphological investigation. Basement software was created by the Eth University of Zurich in 2006 that continues to develop the program producing new freeware version available in the site http://www.basement.ethaz.com..

In particular, this thesis work is contained in a study of the river Iller, a tributary of the Danube in the south of Germany, made by the University of Stuttgart: it begins with a topographical study of the river and the individuation of the human modification made on it and try to understand their consequences in term of hydro and morphological behavior. The study results will support a river development plan, which has to be considered alongside the river for its engineering and morphological aspects as a way take into account the interest of environmental protection.

The work considers only the last part of the Iller starting from the cross section at the 14.6 km until the confluence with the Danube at km 0.0. The grid of the river is build from topographical terrestrial measurement of cross section referred to years 1999 and 2005. An important input data is the complete hydrograph of Iller from year 1953 until 2006, and the measurement of the water level in a specific data for each case, useful for the hydrological calibration. The first step (chapter 5.1) for the creation of the model consist in the hydrological calibration giving as input the discharge measured in the given data and modifying the friction parameter of the cross section until the level of the water computated trace the real one. Moreover, this first part is important to calculate the and mean bottom level of the Iller, necessary for the following part of the work. The second step (chapter 5.2) is the morphological calibration. Since are present in literature different theory model of sediment transportation, for example those of Meyer Peter e Müller, Parker, Weiming-Wu and more, it will be used Basement with different kind of formula. The model will run from 1999 for six years, giving as input the real discharge value registered each day in the real hydrograph. According to the theory used the program will give different kind of bed load transportation. In particular, the sediment transportation plays a fundamental role to understand the veracity and reliability of the model. The theory formula chosen for the present model will produce the best change of mean bottom level: starting from the geometry file of 1999 it must give as output the nearest mean bottom level defined in the 2005 geometry file of hydraulic calibration. The last part of the work focus on the creation of a new hydrograph as input. Once validate the model, the final goal (chapter 6) is to build a continuous discharge that does not change in the period of time considered and that permit to reproduce the same sediment transportation.

1 Sedimentation and morphology model

All sediment particles moving with flowing water are called total load. The total load can be divided into bed load and suspended load as per sediment transport mode or bed-material load and wash load as per sediment source.

The bed load consists of sediment particles that slide, roll, or saltate in the layer several particle sizes above the bed surface. It usually accounts for 5–25% of the total load for fine particles and more for coarse particles in natural rivers. The suspended load is composed of sediment particles that move in suspension in the water column above the bed-load layer. Its weight is continuously supported by the turbulence of flow.

The bed-material load is made up of moving sediment particles that are found in appreciable quantities in the channel bed. It constantly exchanges with the bed material and has significant contribution to the channel morphology. The wash load is comprised of moving sediment particles that are derived from upstream sources other than the channel bed. It is not found in appreciable quantities in the bed. It is finer than the bed-material load and rarely exchanges with the bed material. Einstein (1950) defined wash load as the grain size of which 10% of the bed material mixture is finer.

It should be noted that the definition of wash load and bed-material load depends on flow and sediment conditions. Some wash load in upstream channels may become bed-material load in downstream channels due to the weakening of flow strength. Some sediment particles are wash load in the main channel but may be bed-material load in flood plains

By definition, the bed-material load is the sum of bed load and suspended load. So is the wash load. Because the stochastically averaged properties of a group of sediment particles are mainly concerned in river engineering, sediment is often assumed to be a kind of continuous medium. Two mathematical models can be used to describe the water and sediment two-phase flow based on this assumption. One is the two-fluid model that considers water and sediment as two fluids and establishes the continuity and momentum equations for each phase. The other is the diffusion model that considers the movement of sediment particles as a phenomenon of diffusion in the water flow and hence establishes the continuity and momentum equations for the water sediment mixture and the transport (diffusion) equation for sediment particles. The flow and sediment transport equations used in Basement are based on the diffusion model.

- Mass conservation equation:

$$\frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} - \frac{\partial ql}{\partial t} = 0$$

  Where *ql* represent the sediment flux that enter and exit in the domain.

- Momentum conservation equation:

$$\frac{dM}{dt} = \Sigma F$$

  Where ΣF is the sum of the external force as: pressure of the mixture; stresses of the mixture and gravity. M is the mass into the volume control.

- The transport equation:

$$\frac{\partial C}{\partial t} + \frac{\partial ql}{\partial x} = \frac{\partial u_s}{\partial x}$$

  Where C is the mass concentration in the domain, u_s is the diffusion velocity of sediment.

In the case of non-uniform sediment transport, moving sediment particles collide and interact; bed sediment particles experience the hiding and exposure effects, because fine particles are more likely to be hidden and coarse particles have more chance to be exposed to flow. However, if the sediment concentration is low, interactions among the moving sediment particles are usually negligible, so that each size class of the moving sediment mixture can be assumed to have the same transport behavior as uniform sediment. Each size class is represented by a characteristic diameter, d_k.

1.2 Fundamentals of Sediment Motion

1.2.1 Critical shear stress

The critical shear stress $\tau_{Bcr} = \theta_{cr} (\rho_s - \rho)\, g d_g$ is the threshold for the initiation of motion of the grain class g and is derived from the according Shields parameter θ_{cr} , which is a function of the shear Reynolds number Re*. In the numerical models of BASEMENT, the Shields parameter $\theta_{cr} = f\,(D^*)$ is evaluated as function of the dimensionless grain diameter D*.

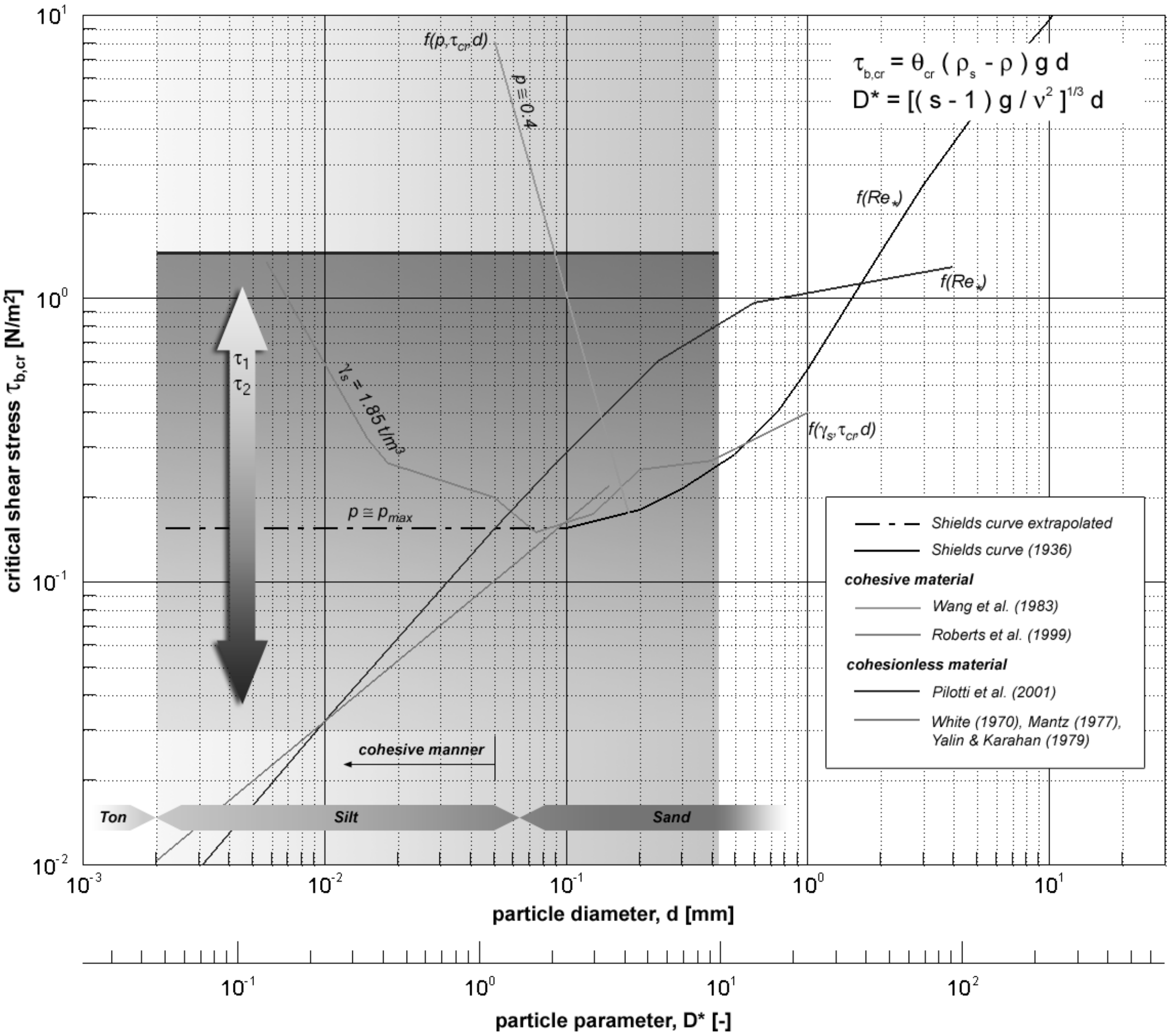


Figure 1:Determination of critical shear stress for a given grain diameter.

The critical Shields parameter θ_{cr} can be set to a constant value or can be determined in the numerical simulations using a parameterization of the Shield's curve.

1.2.2 Influence of Local Slope on Incipient Motion

The investigations on incipient motion by Shields were made for almost horizontal beds. In cases of sloped beds with slopes in flow direction or transverse to it, the stability of grains can either be reduced or enlarged by the acting gravity forces. One approach to consider the effects of local slopes on the threshold for incipient motion is to correct the critical shear stresses for incipient motion.

The corrected critical shear stress then is determined based on slope trend.

1.2.3 Influence of Bed Forms on Bottom Shear Stress

In presence of bed forms, like ripples, sand dunes or gravel banks, additional friction losses can occur due to complex flow conditions around these bed forms and the formation of turbulent eddies. In such cases the dimensionless bottom shear stress θ determined from the present flow conditions can differ from the effective dimensionless bottom shear stress θ′ , which is relevant for the transport of the sediment particles. It is usually assumed that the determination of the effective shear stress should be based upon the grain friction losses only and should exclude additional form losses, to prevent too large sediment transport rates. Therefore a reduction factor μ is introduced for the determination of the effective bottom shear stress θ′ from the bottom shear stress θ as:

- $\mu = \frac{\tau'_B}{\tau_B} = \frac{\theta'}{\theta}$ and μ=1(no bed forms) and μ<1 (bed forms)

This reduction factor (also called “ripple factor”) can be given a constant value if the bed forms are distributed uniformly over the simulation domain. Generally can be said, the larger the form resistance, the smaller becomes the reduction factor μ.

Another approach is to calculate the reduction factor by introducing a reduced energy slope J', compared to the energy slope J, due to the presence of the bed forms as done by Meyer-Peter and Müller. This approach is in particular suitable if ripples are present at the river bed and finally leads to the following estimation of the reduction factor:

$$\mu = \left(\frac{k_{str}}{k'_{str}}\right)^{\frac{3}{2}}$$

1.2.4 Bed Armouring

In morphological simulations with fractional sediment transport the forming or destroying of bed armouring layers can be simulated by modelling sorting effects without special features.

The effects of such a protection layer can be considered using two methods:

- A critical shear stress τ_{cr*} of the protection layer can be specified, which must be exceeded at least once before erosion of the substrate can take place. This method is suited for simulations with one or multiple grain classes: Start of erosion: $\tau_{cr*} > \tau_{cr}$;
- Another approach is to define the d90 grain diameter of the bed armouring layer.The dimensionless critical shear stress $\theta_{cr,armour}$ of this bed armour is then estimated as:

  $$\theta_{cr,armour} = \theta_{cr} \left(\frac{d_{90}}{d}\right)^{\frac{2}{3}}$$

  where d90 is the specified d90 grain diameter of the bed armour and d and θcr are the diameter and critical shear stress of the substrate.

If sediment has accumulated above the protection layer, the armouring condition is not applied until this sediment is totally eroded.

1.2.5 Settling Velocities of Particles

The settling velocity w of sediment particles is an important parameter to determine which particles are transported as bed load or as suspended load. Many different empirical or semi-empirical relations for the determination of settling velocities in dependence of the grain diameter have been suggested in literature.

For example the Approach of van Rijn supposed that the sink rate can be determined against the grain diameter: for different diameter range there are different velocity settling formula.

1.2.6 Bed load Propagation Velocity

The propagation velocity of sediment material is an important parameter to characterize the bed load transport in rivers. In some numerical approaches for morphological simulations this velocity is a useful input parameter.

Several empirical investigations have been made to measure the velocity of bed load material in experimental flumes. One recent approach for the determination of the propagation velocity is the semi-empirical equation based on probability considerations by

Zhilin Sun and John Donahue as:

$u_b = 7.5(\sqrt{\theta'} - C_0\sqrt{\theta_{cr}})\sqrt{(s-1)gd}$;

where θ' is the dimensionless effective bottom shear stress and θ_{cr} is the critical Shields parameter for incipient motion for a grain of diameter d. Furthermore, C_0 is a coefficient less than 1 and s is specific density of the bedload material.

1.2.7 Bed Material Sorting

The change of volume of a grain class g is balanced over the bed load control volume Vg and the underneath layer volume V_{subg} , as it is illustrated in the following Figure 2:efinition sketch of overall control volume of bed material sorting equation (red).:

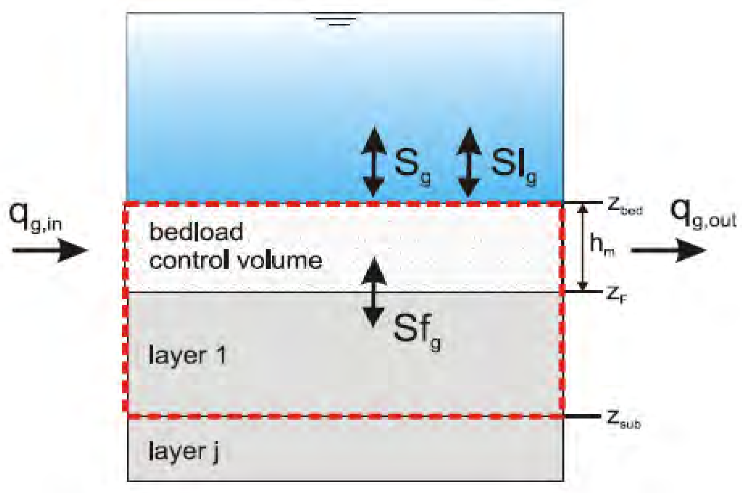


Figure 2:efinition sketch of overall control volume of bed material sorting equation (red).

Depending on the bedload in- and outflows, the composition of the grain fractions in the bedload control volume can change. Futhermore three source terms are distinguished:

- External sediment sources or sinks can be specified (Slg).
- An exchange of sediment with the water column can take place (Sg).
- The movement of the bedload control volume bottom Zf can lead to changes of the grain compositions within the bedload control volume and the underneath soil layer (Sfg). (This is a special kind of source term, because it does not change the overall grain volume within the control volume indicated in the previous fig. It is not related with a physical movement of particles.)

For each grain class g a mass conservation equation can be written, the so called “bedmaterial sorting equation”, which is used to determine the grain fractions β_g at the new time level

The sorting equation is:

$$(1-p)\frac{\partial}{\partial t}(\beta_g h_m) + \frac{\partial q_b}{\partial x} + s_g - sf_g - sl_{Bg} = 0 \quad \textit{for } g=1,\ldots,n$$

Where hm = thickness of bedload control volume, p = porosity of bed material (assumed to be constant),qb = components of total bed load flux per unit width, sf_g = flux through the bottom of the bedload control volume due to its movement and SI_{Bg} = source term to specify a local input or output of material.

2 Mathematical model for Sedimentation and morphology

INTRO

Nowadays, sedimentation and hydraulic processes are object of studies to understand the behavior of the river in the prospective of river engineer measures and environmental processes. The physical study requires too much effort in term of time, reproducibility and money, also because the area of study of the river interests big distance with different kind of environment difficult to develop in one unique experiment. Thanks to the evolution of computer system, most of the river problem are studied with the help of model that, based on transportation theories, can simulate the real behavior of the river and permit a morphological and hydrological investigation on it. The use of models for this kind of study is relatively recent since it begins from the middle of 20th century. The issue of identify the different way of sediment transportation, discerning bed load from suspended transportation and the relation between the layers in the natural flow, begins to be introduced allowing more appropriate studies. Another important assumption was the different grain size distribution in the layer giving the possibility to introduce the armour concept and first of all the heterogeneity of the sediments not only in size dimension but also in shape and density (Wang, 2004). In the former state of modelling evolution, the one-dimensional models were developed to basic situation with well know results, for example for simulate the flow and sediment transport in the main flow direction without solving in details over the cross section. Then the two-dimensional model begin to be used in the case where the vertical (or lateral) variation of flow sediment could be considered small or could be analytically determined, so that the river can be described by a depth-averaged (or width-averaged) 2-D model and the shallow water equation can be analyzed. Classical problems that involves shallow water equation are for example tides in oceans, flood waves in river and dam break. Finally, the three-dimensional models grant the effect of turbulence, free surface and bed change in the river flow considering the Reynolds-averaged continuity and Navier-Stokes equation. The study of braided channels and structures that interact with the river flow, for example bridge piers, require a 3-D model to investigate the complete physic behavior.

Computational models permit analytic solution in hydrodynamic and sediment transport fields involving the numerical solution of one or more of the governing differential equations of continuity, momentum, and energy of fluid along with the differential equation for sediment continuity. The nature of a problem and the availability of data for the calibration and validation allow the choice of the right model to exploit (Papanicolaou, 2008). Furthermore a complex model as 3-d model requires the solution of several equations and a great effort for the computer system and above all in term of time. Because of those problems, in the case of a river that consist of a big area, it is useful to divide the river stretch in subdomains and applying the 1-D model in less important part with simple geometry and the 2-D or 3-D model in subdomains with complex geometry. The "Coupling" fixes the boundary condition in the common edges of two different subdomains based on the conservation of flow flux, momentum and energy as well as sediment flux, bed changes and bed material gradation. (Wu, Computational river dynamics, October, 2004))

In the present work, it will be exploited the software system *BASEMENT*, (Ethz University, 2013) a specific program that gives the possibility of computation of one and two dimensional flows with moving boundaries and appropriate models for bed load as well as suspended load and also allows a morphological investigation. Basement software was created by the Eth University of Zurich in 2006 that continues to develop the program producing new freeware version available in the site http://www.basement.ethaz.com.

The model needs a pre-processing phase where the user inserts the topographical data of the project area. These data are used and modelled within the numerical subsystem that is mainly composed by computational grid, with math-physical modules, in which are applied the governing flow laws and the numerical modules with their method of solving the equation. The output of the numerical system set up the post-processing phase that allows the analysis of the processed data, for example of hydrology sedimentation, soil parameters.

Before describing Basement features it will give a general overview of the nowadays structure of model system and process applied in hydraulic field.

The sediment transportation and in particular the instantaneous movement of the water sediment mixture is governed by the conservation equation of momentum and continuity. The equation system created in this way produce the so-called Saint Venant equation that are the depth-integration of the Navier-Stokes equations. The 1-D and 2-D model equations are obtained via section-, depth- and width- averaging from the 3-D model equations. Any dimensional model needs closure and auxiliary relations to specify the different variable related with the theory developed. The theory formula are taken from (Wu, Computational river dynamics, 2007). Considering Basement software it works only with 1-D and 2-D model so that will follow a short review about the governing equation of each model. In particular, since the work focus on 1-D model it will explained with accuracy in the chapter 3.2.2. Moreover, it will be showed a short review of the most common numerical method for solving the problem equation.

2.1 2D Model equations

The 2-D models can follow two different way of derivation from the 3-D equation: depth-average or width-average. The first one is generally used in river engineer measurements. This model simulates the shallow water flow and it is governed by the depth-integrated continuity and Navier Stokes equations:

$$\frac{\partial h}{\partial t} + \frac{\partial (h\bar{u})}{\partial x} + \frac{\partial (h\bar{v})}{\partial y} = 0\,;$$

$$\frac{\partial \bar{u}}{\partial t} + \bar{u}\frac{\partial \bar{u}}{\partial x} + \bar{v}\frac{\partial \bar{u}}{\partial y} + g\frac{\partial h}{\partial x}$$
$$= -g\frac{\partial z_B}{\partial x} - \frac{1}{\rho h}\tau_{Bx} + \frac{1}{\rho h}\frac{\partial(h(\bar{\tau}_{xx} + (D_{xx})}{\partial x}$$
$$+ \frac{1}{\rho h}\frac{\partial\left(h(\bar{\tau}_{xy} + (D_{xy})\right)}{\partial y} \ ;$$

$$\frac{\partial \bar{v}}{\partial t} + \bar{v}\frac{\partial \bar{v}}{\partial x} + \bar{v}\frac{\partial \bar{v}}{\partial y} + g\frac{\partial h}{\partial y}$$
$$= -g\frac{\partial z_B}{\partial y} - \frac{1}{\rho h}\tau_{Bx} + \frac{1}{\rho h}\frac{\partial\left(h(\bar{\tau}_{yx} + (D_{yx})\right)}{\partial x}$$
$$+ \frac{1}{\rho h}\frac{\partial\left(h(\bar{\tau}_{yy} + (D_{xy})\right)}{\partial y};$$

Where h [m] water depth; g [m/s2] gravity acceleration; P [Pa] pressure; $\bar{u}\ and\ \bar{v}$ [m/s] depth averaged velocity in x and y direction; z_B [m] bottom elevation; $\bar{\tau}_{xx}, \bar{\tau}_{xy}, \bar{\tau}_{yx}, \bar{\tau}_{yy}$ [N/m2] depth averaged viscous and turbulent stresses; $D_{xx}, D_{xy}, D_{yx}, D_{yy}$ [N/m2] momentum dispersion terms.

In the 2-D depth-averaged model, the inlet and outlet boundary flow condition must be specify in the case of subcritical flow, while for supercritical flow it is necessary fix two boundary conditions at each inlet. Moreover in the inflow boundary condition the discharge may be assumed proportional to the local flow depth.

2.2 Numerical method

Considering a problem in a general domain, governed by differential equation with boundary conditions, the numerical solution is described by a number of points belonging to the domain. The distance between two consecutive points is the grid size.

Generally, (Wu, Computational river dynamics, 2007) a numerical solution of a differential system equation could be found through numerical method that could be discretization methods that include finite difference method, finite element method, finite volume method and finite analytical method. The finite difference method discretizes a differential equation by approximating differential operators with difference operators at each point. In the finite element method, the differential equation is multiplied by a weight function and integrated over the entire domain, and then an approximate solution is constructed using shape functions and optimized by requiring the weighted integral to have a minimum residual. The finite volume method integrates the differential equation over each control volume, holding the conservation laws of mass, momentum, and energy. The finite analytical method discretizes the differential equation using the analytical solution of its locally linearized form solution. Although the classic finite difference and the finite volume method adopt structured and regular meshes, they encounter difficulties in conforming to the irregular domains of river flow, on the orhet hand the finite element method adopts unstructured, irregular meshes and can conveniently handle such irregular domains. Therefore, it has been a trend in recent decades to develop the finite difference and finite volume methods on irregular meshes, which have the grid flexibility of the finite element method and the computational efficiency of the classic finite difference and finite volume methods. (Wu, Computational river dynamics, 2007)

Basement software will be described in the following chapter in all his multiple aspects and functions: Basement solves the differential equation with the Finite Volume method with moving boundaries.

3 Basment software

Since the present work consider the morphological evolution of the river Iller in a one-dimensional system, it will be exploited the software system "*BASEMENT*" (basic-simulation-environment).The program provide a functional environment for numerical simulation of alpine rivers and sediment transport involved. The numerical models gives the possibility of computation of one and two dimensional flows with appropriate models for bed load and suspended load allowing a morphological investigation. Basement software was created by the Eth University of Zurich in 2006 that continues to develop the program producing new freeware version available in the site http://www.basement.ethaz.com.

The Software system BASEMENT is composed of the executable (binary) file BASEMENT: its purpose is the simulation of water flow, sediment and pollutant transport and according interaction in consideration of movable boundaries and morphological changes.

3.1 Employment domains

The program software (Ethz University, 2013) provide the solution of the common river engineers problems allowing reliable computation. The software permit to calculate several problem in relation with the sediment transport of watercourses and for example help to predict the evolution of the mean bottom of the channels. An important feature of Basement is that it gives, once calibrated the model, the possibility to confirm the consequences of a measure that interest the river for make the necessary evaluation before their application.

BASEMENT has the following fundamental capabilities:

- Simulation of flow behavior under steady and unsteady conditions in a channel as well as its transition;

- Simulation of sediment transport (both bed load and suspended load) under steady and unsteady conditions in a channel with arbitrary geometry;
- Sediment transport of water courses, for instance the future development of deltas and alluvial areas, the long-term evolution of the bottom channels;
- The modification of the channel geometry, as this can be the case for example for revitalizations or protection measures, where the consequences of the interventions have to be evaluated;

3.2 Basement structure

Basement consist of pre- and post- processors, that can be performed with independent products, and the numerical subsystem, which is the core of the numerical solutions algorithms.

The pre-processing activities defines the input data, that describe the study area, in the right format to satisfy input specifications as the main computation program:

- Topographic data: based on the real world data describing the cross section;
- Hydrologic data: time series of flow discharge, water levels or concentration of suspended sediments;
- Granulometric data: grain size distributions from water-, sediment- or line samples.

The post-processing activities consist of the understanding of the output data produced from the numerical elaboration of the system: analysis of the hydrology, sedimentology and soil parameter results often with the help of program like Excel.

The numerical subsystem in one dimension is called BASEchain. The components of the numerical model can be subdivided into:

- the computational grid representing the discrete form of the topography;
- the mathematical-physical modules consisting of the governing flow equations and the main transportation laws;
- the numerical modules are made of methods for solving the equations;

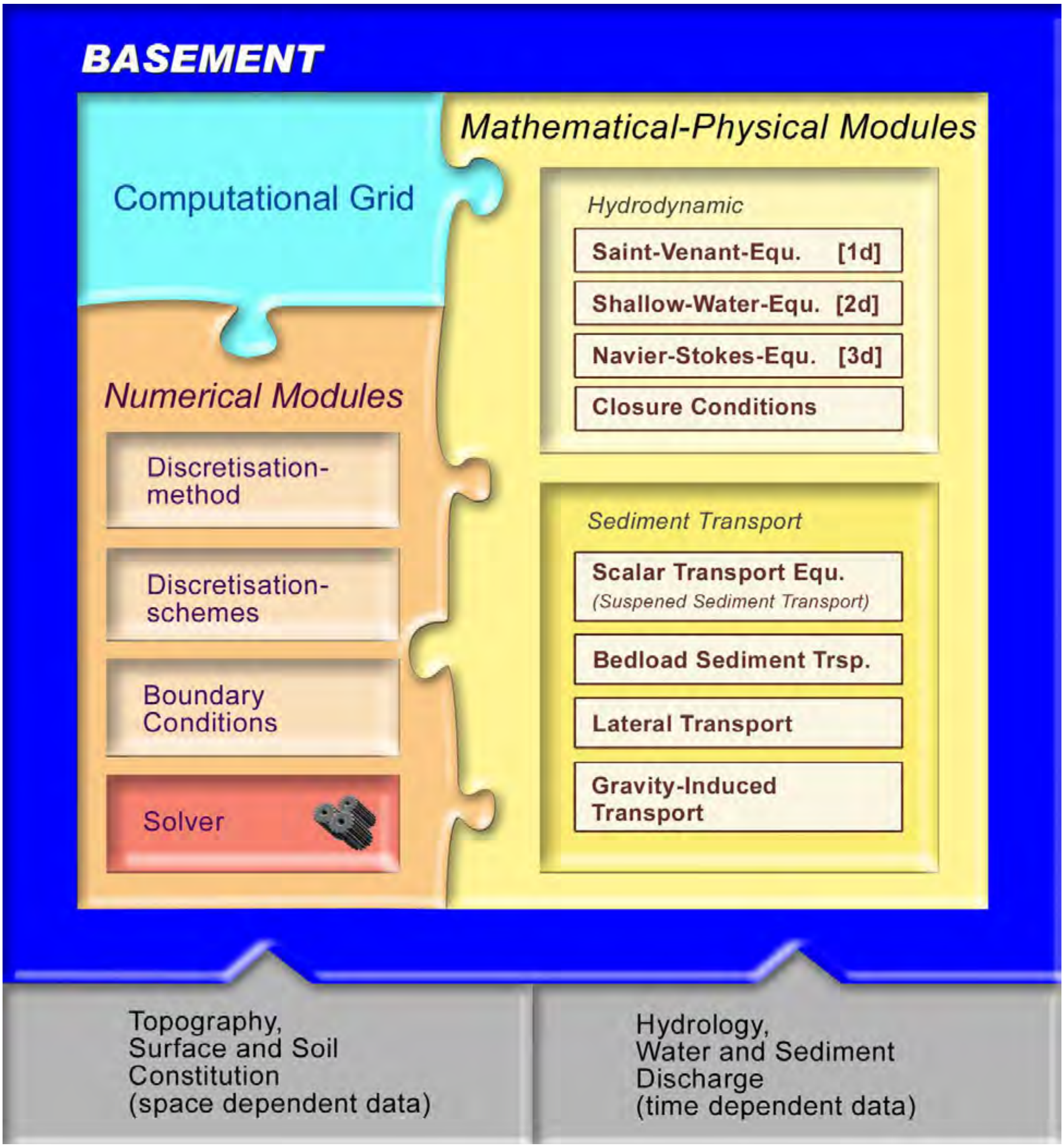


Figure 3: Modules and their Components.

3.2.1 Computational Grid

An important aspect of every computational task is the grid generation where the real world topography data is transformed into an internal computational grid on which the governing equations are solved. Building the grid, is fundamental a great accuracy for the veracity of the model: generally is required a dense region in the stretch where strong changes in the flow occur (Ethz University, 2013).

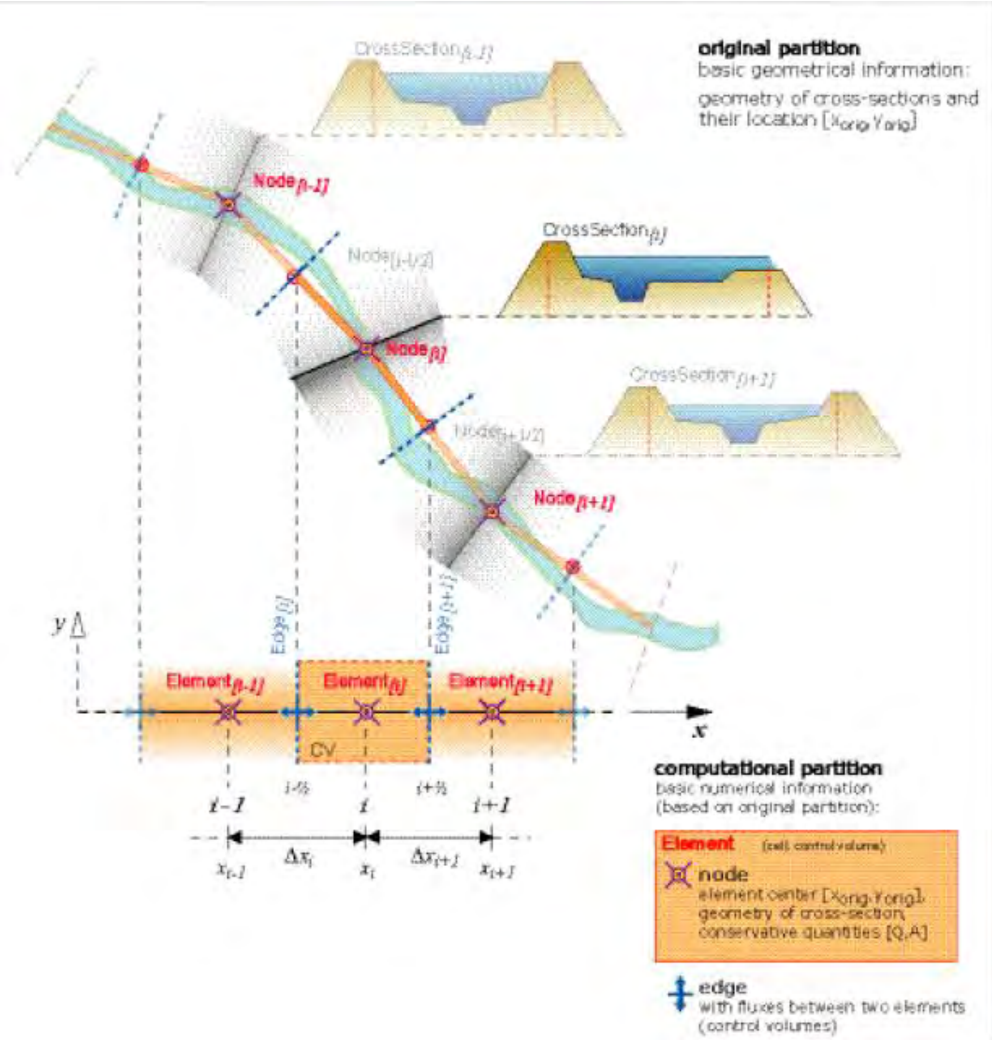


Figure 4: Discrete Representation of the Topography within BASEchain.

The aim of the computational grid is to create a mesh of the river. In one dimension model, an element, that is the place where the physical variables are defined, consists of two nodes with known cross-section where the elevation information has to be mapped. With a cell-centered discretization, all variables, for example velocity, flow depth and cross-section geometry, are defined at the location of the nodes. The midpoint of the connecting line between two nodes defines the common edge of the two elements.

3.2.2 Mathematical – Physical – Modules

As seen, the development of a fluid and in particular, of a river can be analyze with physical models that are mainly governed by the conservation of mass and momentum. Theoretically, it is possible to resolve the mathematical problem up to small-scale phenomena like turbulence structures. In a natural problem however, it is mostly impossible to determine all boundary and the exact initial conditions. Furthermore, the computational time needed to solve the full equation system is increasing very fast with higher spatial and temporal resolution. Therefore, depending on the problem, simplified mathematical models are used (Ethz University, 2013).

In three dimension, the flow and the pressure distribution are completely described by the Navier-Stokes equations, which include the whole physics forces acting in the water flow. Assuming a static pressure and neglecting the vertical flow components, the equations simplify to the two-dimensional shallow water equations, useful to determinate the behavior of water level and velocities in a plane. Reducing the spatial dimensions one more results in the 1-D Saint-Venant equations.

A schematical analysis of the transportation flow provide a division between suspended sediment and bed load. The sediment transport and behavior of the riverbed are computated using empirical formulas developed by river engineers and researchers.

3.2.2.1 Hydrodinamic

Within the program, the computational phase in one dimension is called BASEchain module and it is based on the Saint-Venant equations for unsteady dimensional flow (Ethz University, 2013). The equation is obtained from the Navier-Stokes equation assuming the following hypothesis on the flow:

- hydrostatic distribution of pressure,

- uniform velocity over the cross section,
- small channel slope and steady-state resistance laws for unsteady flow.

The Saint-Venant equation can be described as conservation of mass and momentum applied in a defined volume control.

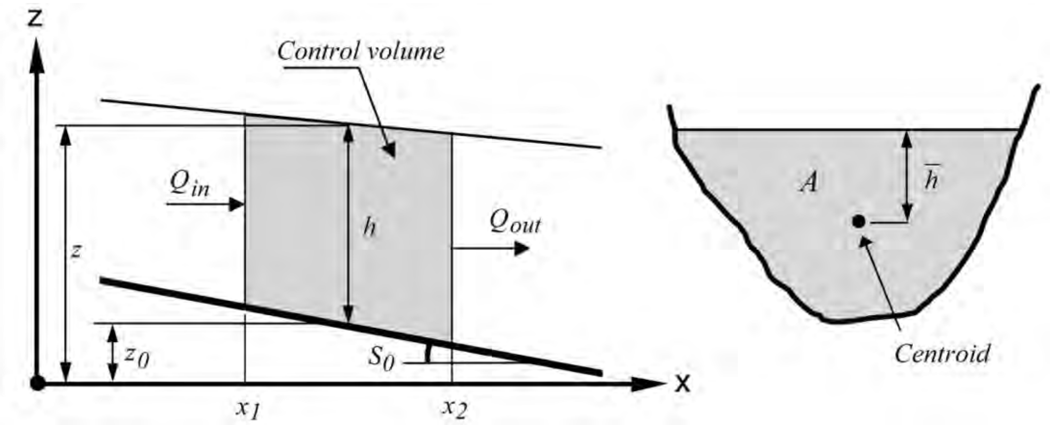


Figure 5: Volume control (basement reference)

3.2.2.1.1 1-D Mass conservation

Considering the volume control shown in Figure 5 and assuming the mass density ρ constant:

$\frac{d}{dt}\int_{x1}^{x2} Adx + Qout - Qin - ql\,(x2 - x1) = 0$;

Where *A* is the wetted cross section area, *Q* is the discharge, q_l is the lateral discharge per meter of length, *V* is the volume, *x* is the distance and *t* is the time.

The divergent form of the continuity equation is obtained applying the Leibenitz's rule and the mean value theorem, $\frac{d}{dt}\int_{x1}^{x2} Adx = \frac{\partial A}{\partial t}(x2 - x1)$, with the annotation that $\frac{Q_{out}-Q_{in}}{(x_2-x_1)} = \frac{\partial Q}{\partial x}$, from the former equation results the 1-d continuity equation:

$$\frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} - ql = 0$$

3.2.2.1.2 1-D Momentum Conservation

According to the Newton's second law of motion, and making use of Reynolds transport theorem the second governing equation is:

$$\frac{dM}{dt} = \Sigma F = \frac{d}{dt}\int_{x1}^{x2} u\rho A dx + u_2\rho A_2 u_2 - u_1\rho A_1 u_1 - u_x\rho q_l(x_2 - x_1)$$

Where M is momentum; F is force; u_x is velocity in x direction (direction of flow) of lateral source; $u_{1,2}$ represent the in-outcoming velocity into the volume control; ρ is mass density.

The final equations needs the specifications of the force that act on the control volume and that define ΣF:

- Pressure force upstream and downstream: $F_1 = \rho g A_1 h_1$; $F_2 = \rho g A_2 h_2$;
- Weight of water in x-direction: $F_3 = \rho g \int_{x1}^{x2} AS_b dx$;
- Frictional force: $F_4 = \rho g \int_{x1}^{x2} AS_f dx$;
- S_b represent the bottom slope; S_f is the friction slope $S_f = \frac{|Q|Q}{K^2}$;
- $K = k_{strickler}AR^{2/3}$ is the conveyance factor (R=hydraulic radius).

The equation results:

$$\frac{\partial Q}{\partial t} + \frac{\partial}{\partial x}\left(\frac{Q^2}{A}\right) + gA\frac{\partial z_s}{\partial x} + gAS_f - q_l u_x = 0$$

In the model are used only the cross sectional area where the water actually flows, so it is introduced a factor β accounting for the velocity distribution in the cross section. The final equation is:

$$\frac{\partial Q}{\partial t} + \frac{\partial}{\partial x}\left(\beta\frac{Q^2}{A_{red}}\right) + gA_{red}S_f - q_l u_x = 0$$

Where A_{red} is the reduced area: the part of the cross section area where water flows; β is defined with the use of strickler value:

$$\beta = \frac{A\sum_t {k_{strick}}^2 {h_i}^{7/3} b_i}{(\sum_t k_{strick} h^{5/3} b_i)^2}$$

3.2.2.1.3 Mass term

With the given formulation of the flow equation there are 4 source terms:

For the continuity equation:

- The lateral In- or Outflow q_l ;

For the momentum equation :

- The bed slope: $W = gA\frac{\partial z_s}{\partial x}$;
- The bottom friction: $Fr = gA_{red}S_f$;
- The influence of the lateral In- or Outflow $q_l u_x$.

3.2.2.1.4 Closure Conditions: Determination of Friction Slope

The relation between the friction slope Sf and the bottom shear stress is:

$$\frac{\tau_B}{\rho} = gR\, S_f$$

As the unit of τ/ρ is the square of a velocity, a shear stress velocity can be defined as:

$$u_* = \sqrt{\frac{\tau_B}{\rho}}$$

The velocity in the channel is proportional to the shear flow velocity and thus:

$$u = c_f\sqrt{gRS_f}$$

where $c_f$is the dimensionless Chézy coefficient. It is defined as $c_f = \frac{C}{\sqrt{g}}$.

The determination of the friction coefficient is based either on the approach of Manning-Strickler K_{str}.

To define the channel roughness, both notations, K_{str} or n , can be used. For conversion a simple relation holds:

$$K_{str} = \frac{1}{n}$$

3.2.2.1.5 Boundary conditions

In the extreme edge of the channel is necessary to know the influence of the outside region on the flow within the computational domain. The fundamental value that characterize the influence area is the velocity of propagation $C = \sqrt{gh}$, that should be added to the velocity of the river. In a one dimensional flow the propagation could take place in two directions: upstream(C_-) and downstream(C_+):

$$C_{\pm} = \frac{dx}{dt} = u \pm c$$

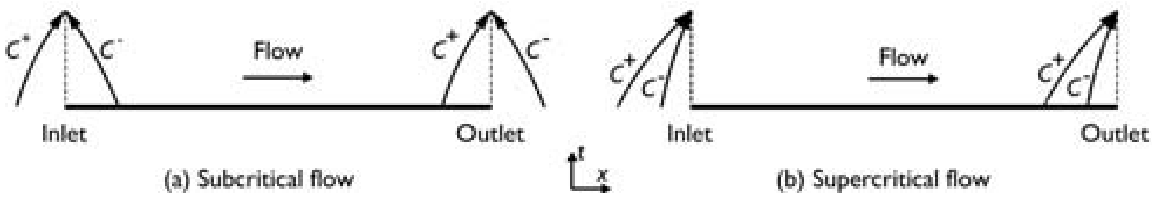


Figure 6:Characteristic curves of dynamic wave model at inlet and outlet boundaries.

In the case of supercritical flow results *c<u* and the the information will not be able to spread in upstream direction, thus the condition in a point can not influence any upstream point: two boundary condition must be referred in the inflow. On the other hand, in the sub-critical flow, c>u and the information spreads in both directions, upstream and downstream and it is necessary to assign the boundary condition either in the outflow and in the inflow.

	Number of boundary conditions	
Flow type	*Inflow*	*Outflow*
Sub critical flow ($Fr < 1$)	1	1
Supercritical flow ($Fr > 1$)	2	0

Tabella 1:Number of needed boundary conditions

The boundary conditions commonly could indicate the outflowing discharge by a weir or a gate, or a water surface elevation as a function of time or as a function of the discharge.

3.2.2.2 Sediment transport

3.2.2.2.1 1-D Bed load transport

The bed load flux for the one-dimensional case consists of one single component for each grain size, namely the specific bed load flux in stream wise direction q_{Bg}. The mechanism of the transportation is governed by the following equation:

3.2.2.2.2 Bed load transport due to stream forces

The total specific bed load flux due to stream forces is evaluated as follows:

$$q_{Bg} = \beta_g q_B(\xi_g)$$

The different approach of the transport Formula leads to different evaluation of q_B with or without the consideration of the hiding factor ξ_g ; β_g *is* grain fraction.

3.2.2.2.3 Bed material sorting

For each grain class g a mass conservation equation can be written, the so called “bedmaterial sorting equation”, which is used to determine the grain fractions β_g at the new time level

The sorting equation is:

$(1-p)\frac{\partial}{\partial t}\left(\beta_g h_m\right)+\frac{\partial q_b}{\partial x}+s_g-sf_g-sl_{Bg}=0$ *for g=1,…,n*

Where h_m = thickness of bedload control volume, p = porosity of bed material (assumed to be constant),q_b = components of total bed load flux per unit width, sf_g = flux through the bottom of the bedload control volume due to its movement and sl_{Bg} = source term to specify a local input or output of material; s_g = describes the exchange per unit width between the sediment and the suspended material.

3.2.2.2.4 Global Mass Conservation

Finally, the global equation of bed material conservation is obtained by adding up the masses of all sediment material layers between the bed surface and a reference level for all fractions (Exner-equation) directly resulting in the elevation change of the actual bed level:

$$(1-p)\frac{\partial z_B}{\partial t}+\sum\left(\frac{\partial q_{Bg}}{\partial x}+\frac{\partial q_{Bg}}{\partial y}+s_g-sl_{Bg}\right)=0$$

Where z_b is the bed bottom level.

3.2.2.2.5 Sublayer Source Term

The bottom elevation of the bed load control volume z_f is identical to the top level of the underneath layer. If z_f moves up, sediment flows into this underneath layer and leads to changes in its grain compositions. The exchange of sediment particles between the bed load control volume and the underlying layer is expressed by the source term:

$$sf_g = -(1-p)\frac{\partial}{\partial t}((z_F - z_{sub})\beta_{sub\ g})$$

The transport formula used for the evaluation of q_b will expose in the cap(..)

4 Area of interest:

The Iller (Wieprecht, 20.11.2013) is a right tributary of Danube and it is 147 km length. The source is located in the south of Germany close to the Austrian boundary, it arises in the Allgäu region of the Alps at Oberstdorf, and it flow directly into the Danube above Ulm. With the Parisian treaty of 1810 the Iller forms border between Wüttemberg and Bavaria and it is still valid today since a correction of the course in 1826.

Figure 7: Iller localization (de.wikipedia.org)

The drainage basin of the Iller contains about 2152 km^2, of which belongs about 68% on Bavarian, 27% on Baden-Wuttemberg and the other 5% upon Austrian territory. About one third of the catchment area of Iller is in the high mountains and since the influxes have only a little influence on the flow in the lower stretches of the river, the Iller on the whole length has a typical pre-alpine drain character with a simple drain regime. Owing to the relatively restricted catchment area, rapid and intense rain events can already lead to the quick increase in the drain.

On its flowing way it cuts the Northern Limestone Alps, the Flysch Zone and the Helvetic, and flows then in the Möraine area of the Pedimont Glacier. The Iller is subdivided in three areas based on landscape types and nature spatial structure: the Upper Iller (km 149 - km 103) flows in the Alps as a mountain river; the Middle Iller (km 103 - km 59) flows through the foothills of the Alps; the lower Iller (km 59 – km 0) passes throughout the Bayern – Swabian plateau. Both the Middle and the Lower are intensively exploit for electricity generation. While in the area of the Middle Iller are located hydroelectric power stations, which interrupt the debris transport, in the Lower stretch power station are built out line. Weirs and other crossways buildings, which were built to the support of the river sole, handicap also the sediment transport regime in the course of the main channel of the Lower Iller.

Before the correction during the years 1860-1900, the Iller was in the study area (km 56,725 - km 0) in a braided river bed of 600 m to 1000 m wide, thereafter it was straightened and expanded with a trapezoidal normal profile of 52 m bottom width. Due to the profile narrowing, occurred a shortening of the length by 16%, a rise of the river slope from about 0,18% to 0,22%, also turn up a strong increase of the bottom level (up to 4.5 m) and a lowering of the groundwater table. Already in the year 1901 the depression of the river bottom level was in the area of Ferthofen (km 56,725) up to the Efelseer bridge (approsimately km 45,0) between 1,6 and 4,5 m.

Since the flood in the corrected bed of Iller flows with depth of 5 m to 6 m, approximately two meters higher than before (the maximum water depth was 4 m), occur significant correction of the bed shear stress. The increasing of bed shear stress with the sediment deficit, due to the construction in the upper part of Iller of weir and hydropower station, caused a growth of erosion force with a consequent increasing of the medium slope of the river. Despite the water extraction, the bed erosion could not be reduced especially in the event of flooding, therefore it was decided as operation of stability the gradual installation of sills, which was completed in the 1960s. Rough ramps were built in km 20.20 since the year 1998. In accordance with the requirement of the European Water Framework Directive the river bottom uniformity can be ensured. The last ramp was built in 2006 in the km 15,8.

4.1 Aim of the Morphological study

The Lower Iller ((Wieprecht, 20.11.2013) is classified as a heavily modified water body in the study area (km 56,725 till the mouth). Hydro-morphology deficit are the most relevant in the last stretch. The morphological study show in an integral view of the almost 60 km long route to its confluence with the Danube and establishes how to ensure the stabilization of the sole and at the same time how could be realized the proposed guideline measure proposed by the Water Framework Directive CE WFD.

In particular, the study aims provide answers to the following questions:

- What effects would be expected if in the long run no measures are introduced?
- Are the previously implemented remedial measure suitable to achieve the objects in terms of riverbed stability and continuity?
- What measures has to be executed in order to achieve the objectives in terms of bed stability and continuity in the future in a sustainable way?
- Which crossways buildings are required for the long-term soling transport?
- What are the impacts for the ground water conditions of the measures proposed for the protection from flood and existing hydropower?
- How can sediment be mobilized within the study section (for example by lateral erosion) to contribute the support of the sole and the achievement of good ecological potential?

5 Calibration and validation

The steps of my thesis consist in:

- Creating a mesh grid of the Iller, strating from real measurements of two different year data set;
- Calibrating the hydrodynamic of the model, studying the variation of the Gauckler Strickler friction factor, in order that the surface water level of each project coincide with the corresponding measured data;
- Calibrating the morphology of the model appointing in the different stretch of the river the grain size distribution measured on the field and implementing the model with different theory formula. The mean bottom level line, calculated in this way, should coincide with the real data conform of 2005, running the model from 1999 for six years. The input file is made of the real discharge taken from the record value of the Iller hydrograph;
- Creating the new input hydrograph allowing to reproduce the same bed load transportation with a continuous discharge that does not change in value in the six years of simulation.

In this specific case of study data refers to the 1999 and 2005 year. The Iller's section recreated start from the km 14.6 till the confluence with Danube near Ulm city km 0. The data sets of year 2005 gives a limited number of cross section so it begins from km 9.2 and ends in the km.0. Once calibrated the model, an important goal is to create the missing cross section in the 2005 geometry file.

5.1 Hydraulic calibration:

The first part of the work consist in modelling the mash available from the terrestrial measurement, made in different years, of the Iller cross section.

The measurement gives info on:

- Topographic data: described by three dimensional coordinates;
- Hydrologic data: time series of flow discharge, water levels;
- Granulometric data: grain size distribution from sediment sample (general).

The data refers to the 1999 and 2005 year, thus a separate grid needs to be set up for all three of them.

5.1.1 Structure and concept of the Hydraulic calibration

The hydraulic calibration consist of running the model using a steady inflow hydrograph. After a certain run time, approximately one day, the simulation should reach a steady water surface level. The level registered in the output file will thus compared with real measurement realized in the whole stretch of river in a certain data (one for each project). The discharge of each simulation will be referred to the value registered in that specific data. Since we are studying a natural stream, it is reasonable assuming the uniform water flow associated with the Gauckler Strickler law. The core of calibration focus on the modifying of Ks value:

- as first step it will be looked for the general value that best reproduce the real water level;
- then the work will focus on the single cross section Ks value so that the difference of water level between the measured and modelled flow amount to a very small value(cm).

Since the flood plains are covered with grass, stones and sand, but there are also zones with trees thus the most probably value of the Strikler coefficient should be around 38 $m^{1/3}/s$ .In the considered stretch, Iller crosses three bridges (km 2.2, 2.6 and 8.8) and one weir (km 9.5). Those construcitions influence the normal flow of the river but they will not be insert within the domain grid. They will be taken into account with a very low value of Ks value .

Figure 8: Bridges km 2.2, 2.6 (left) and km 8.8 (right).

Figure 9: Weir km 9.5 from google.maps

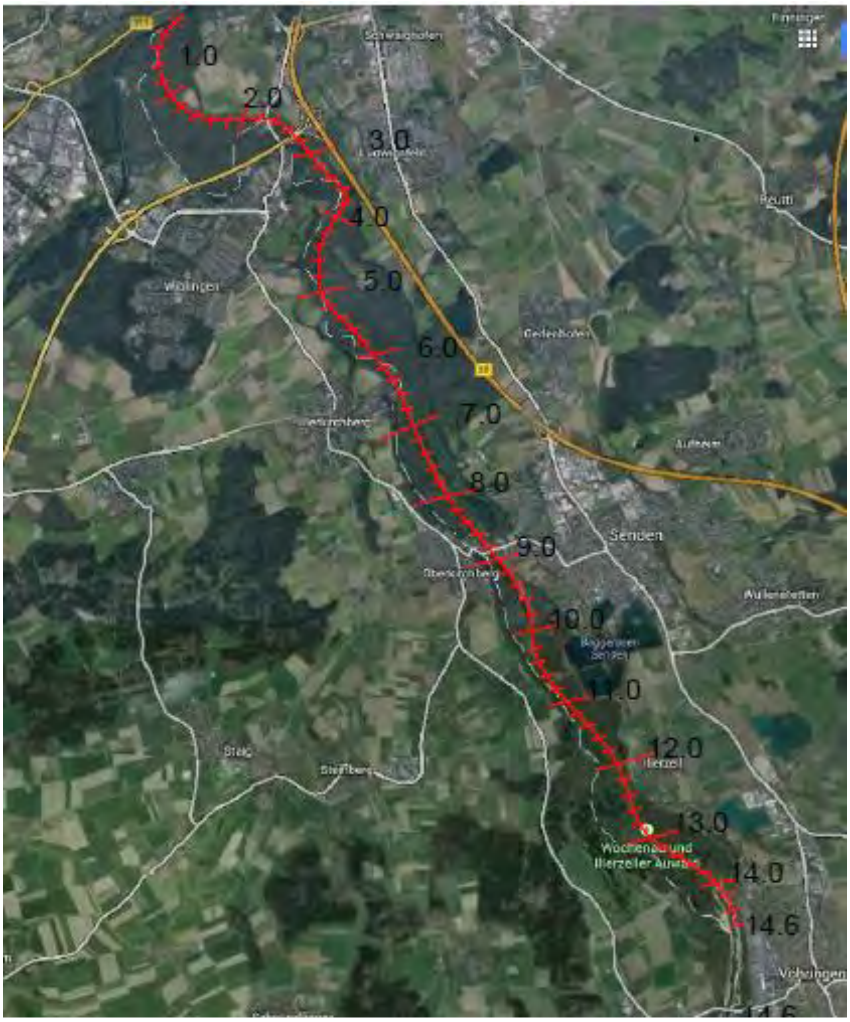


Figure 10: Iller terrestial view from google.maps

5.1.2 Geometry

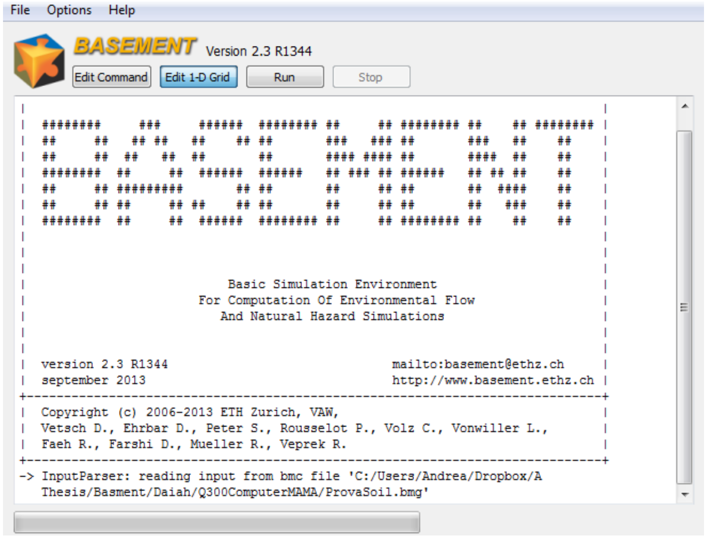


Figure 11: Basement main window.

Basement main window, using the "Edit 1-D Grid" tab, gives the possibility to create a "geometry_file.bmg" within all cross section important data. Every element in the computational grid is defined with topographical information referred to the Gauss-Boaga georeference system as a sequence of point that represent the geometry of the riverbed and with the distance from the upstream to the point of confluence in the Danube. The cross section are defined as a row of x, y, z data gathered for the same distance from upstream. The shape of the area must be created as a series of point with a ((x,y),z) relation, that start from the extreme left point of the bank with a crescent order of distance value. The x,y relation is given as the distance in x,y system between two consecutive point:

$$Distance = \sqrt{(x_i - x_{i-1})^2 + (y_i - y_{i-1})^2}$$

Fkm	X	Y	Z	Distance	Z
0.40	4349750	5361993	471.08	0	471.08
0.40	4349753	5361992	471.13	3.6598694	471.13
0.40	4349756	5361992	471.40	6.15052553	471.40
0.40	4349756	5361992	471.61	6.51023236	471.61
0.40	4349756	5361992	471.42	6.6207086	471.42
0.40	4349758	5361991	471.30	8.05033128	471.30
0.40	4349760	5361991	470.65	10.5105737	470.65
0.40	4349763	5361990	470.31	13.450204	470.31
0.40	4349765	5361990	469.04	15.2599167	469.04
0.40	4349766	5361990	468.96	16.6703042	468.96
0.40	4349767	5361990	468.56	17.5103858	468.56
0.40	4349767	5361990	468.41	17.7504128	468.41
0.40	4349769	5361990	467.76	19.1701667	467.76
0.40	4349771	5361989	467.88	21.5705687	467.88
0.40	4349773	5361989	467.99	23.7998287	467.99
0.40	4349776	5361988	468.01	26.4504484	468.01
0.40	4349779	5361988	468.12	29.2602061	468.12
0.40	4349781	5361988	468.13	31.8603515	468.13
0.40	4349784	5361987	468.14	34.339829	468.14
0.40	4349787	5361987	468.10	37.2600628	468.10
0.40	4349789	5361986	468.09	39.8003677	468.09
0.40	4349792	5361986	468.13	42.349716	468.13
0.40	4349794	5361985	468.15	45.0399541	468.15
0.40	4349797	5361985	468.20	47.7403839	468.20
0.40	4349799	5361985	468.28	50.2897322	468.28
0.40	4349802	5361984	468.27	53.0205757	468.27
0.40	4349804	5361984	468.39	55.3805337	468.39
0.40	4349808	5361983	468.57	58.7799938	468.57
0.40	4349810	5361983	468.62	60.8703378	468.62
0.40	4349812	5361982	468.79	62.9202378	468.79
0.40	4349813	5361982	469.59	64.0105369	469.59
0.40	4349815	5361982	470.39	65.6703164	470.39
0.40	4349816	5361982	471.19	67.1597794	471.19
0.40	4349818	5361982	471.51	68.7304531	471.51
0.40	4349819	5361981	471.38	70.2401382	471.38
0.40	4349821	5361981	470.93	72.2403894	470.93
0.40	4349823	5361981	470.61	73.9304214	470.61
0.40	4349824	5361981	470.72	74.9498629	470.72
0.40	4349825	5361980	471.49	76.5904073	471.49
0.40	4349827	5361980	472.30	77.910702	472.30
0.40	4349830	5361980	472.43	81.1207717	472.43
0.40	4349830	5361980	472.79	81.2301015	472.79
0.40	4349830	5361980	472.39	81.3507705	472.39
0.40	4349831	5361979	471.82	82.7803932	471.82
0.40	4349832	5361979	471.34	83.590061	471.34
0.40	4349834	5361979	470.79	85.1697781	470.79
0.40	4349836	5361978	470.88	87.8001758	470.88

Table 1: Example of data transformation in (X,Y);Z relation

Additionally must be specified the global coordinates of the extreme left point and the orientation angle of the section: these information give the possibility to calculate curvature between the elements. Other important tools are the “Bottom_range” that detail the active zone of the river bed, and the “Friction_coefficient”. This last parameter is really important because when it is defined for a specific section it means that during a simulation with a general friction value set to the whole length of the river, that specific section simulates with his own appropriate friction value. It is very useful for hydraulic calibration of the river. Moreover there is the possibility to appoint different kind of coefficient friction to the same cross section in order to distinguish the bottom from the bank of the river, where vegetation variety often influences in different way the river flow. Finally, the tabs “main channel”, “water flow” and “active” are used when there are problem with the simulation computation, and allow to force the flow within the range set.

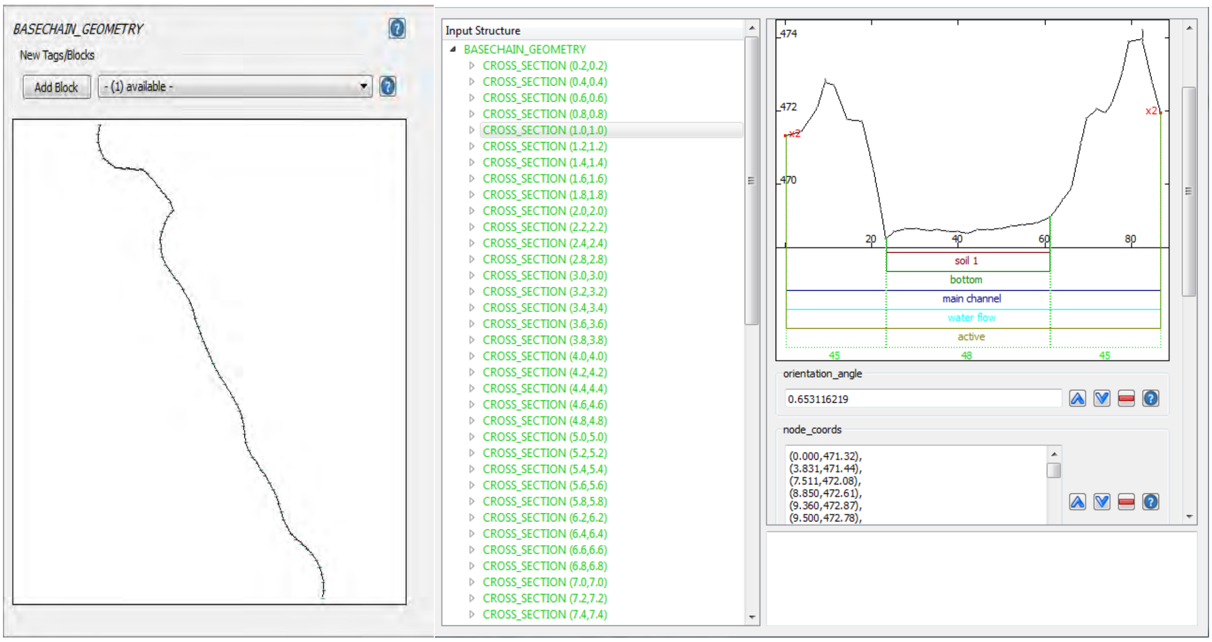


Figure 12:Iller displayed in the region view in the region view of graphical user interface and cross section sample.

Since are available Iller measurement of different years, the first step consist of creating two different mash grid.

Opening the “Edit command” tools, from the main window of Basement, is possible to compile the project with Domain, Boundary conditions, Input file, and all information mandatory for a 1-D simulation. The Domain permit to describe the Geometry, Hydraulics, Morphology and Timestep block. In the hydraulic calibration the Morphology is not essential therefore it will be neglected in this first phase. Geometry block refers to the “geometry_file.bmg”, previous described, and gives the possibility to select the cross section of the file to analyze. Time step block is important to assign the total run time of the simulation and other parameters that influence in term of computational stability. The hydraulic block is really important because contains the sub-block useful for the hydraulic calibration, goal of this first part of the work, and in particular the friction factor.

- *Friction*: in this project, the friction law is set to follow the Gauckler-Strikler theory assigning to all the element belonging to the volume control, where no explicit value has been supplied in the file.bmg, the corresponding “default_friction” value. Strikler coefficient is the main parameter used to make the hydrological calibration.
- *Boundary condition* must be assigned for the upstream and downstream. The upstream inflow is fixed by the hydrograph in which the program read in the input file the appointed discharge in the different time steps. It is also required the slope in order to calculate the normal flows depths. The downstream condition fixed is “zero_gradient” in which the main variables within the last computational cell remain constant over the whole element.
- *Initial* defines the state of the channel at the beginning of the simulation and for the hydrological calibration is fixed dry, representing an empty channel.
- *Parameter* sets the “minimum_water_depth” for which the channel has to be considered dry and also the type and parameter for the computation of hydraulic characteristic cross section. In the project, I set the “iteration” type where the water

level for a given wetted area is calculated iteratively and all other hydraulic parameters are computed at each time step.

The real hydrograph of the iller is shown in the following Figure and it strats in Genuary 1999 and ends in December 2005.

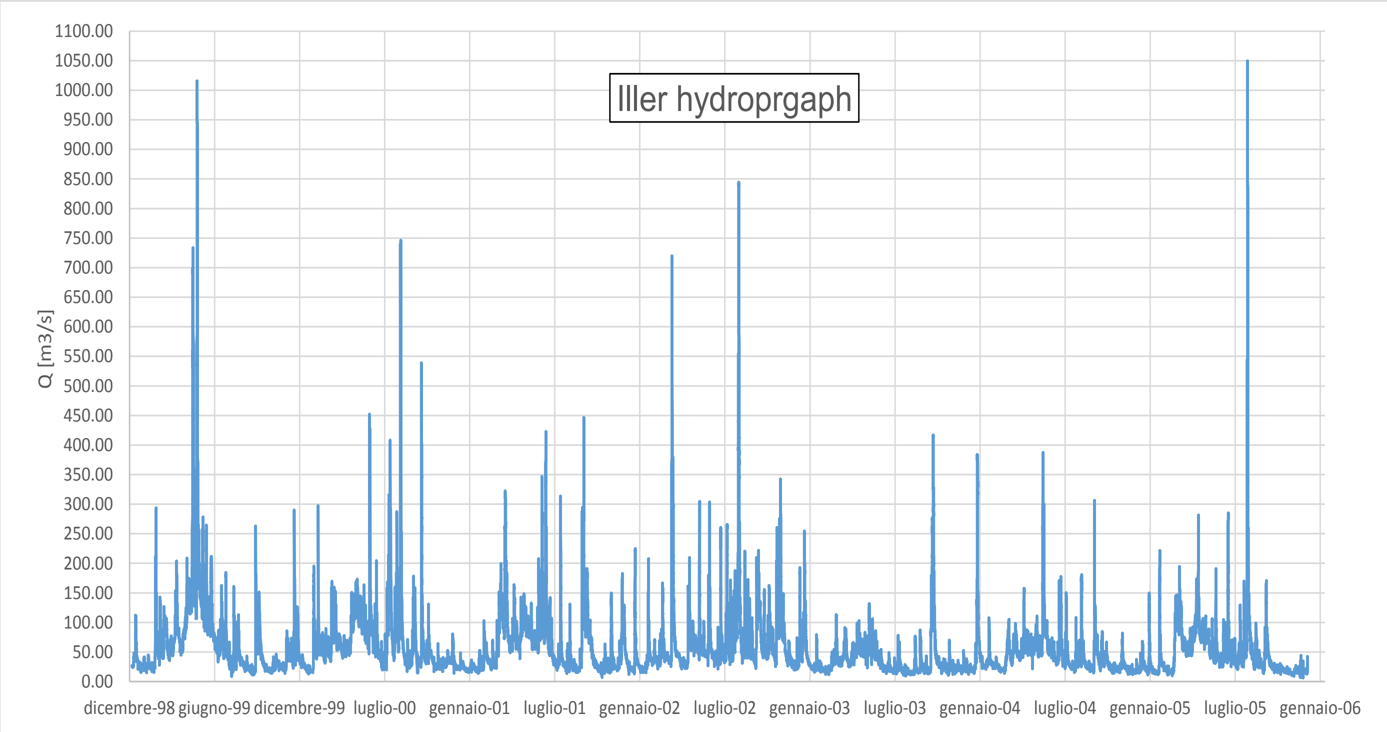


Figure 13: Iller Hydrograph 1999/2005

5.1.2.1 1999

The measured data for the creation of the geometry file of this project refer to May 1999: mean bottom level, mean discharge and water level averaged over the month. The discharge taken is the average value of the real registered data of that month: 258,97 m^3/s. The general value of Ks for the whole channel are: 36, 38 and 40 $m^{1/3}/s$.

km	Aggregate Ks	(L) River Bank	River Bed	(R)River Bank	km	Aggregate Ks	(L) River Bank	River Bed	(R)River Bank
14.6	37				7.2		45	48	45
14.4	33				7	35			
14.2	30				6.8	30			
14	25				6.6				
13.8					6.4	37			
13.6	40				6.2				
13.4					6				
13.2					5.8				
13		44	48	44	5.6		46	48	46
12.8					5.4		46	48	46
12.6	44				5.2				
12.4	46				5				
12.2	46				4.8				
12		45	48	45	4.6				
11.8		45	48	45	4.4				
11.6		42	45	42	4.2		30	35	30
11.4					4		30	35	30
11.2					3.8	34			
11	34				3.6				
10.8		24	28	24	3.4				
10.6					3.2				
10.4		44	46	44	3	28			
10.2					2.8	28			
10					2.6				
9.8	44				2.4	30			
9.6	25				2.2		34	36	34
9.4		18	22	18	2		24	26	24
9.2		18	22	18	1.8	38			
9		34	35	34	1.6	28			
8.8		24	26	24	1.4	28			
8.6					1.2				
8.4	26				1		45	48	45
8.2	35				0.8		45	48	45
8	35				0.6	42			
7.8	31				0.4				
7.6	28				0	31			
7.4	42								

Table 2: Ks distribution.

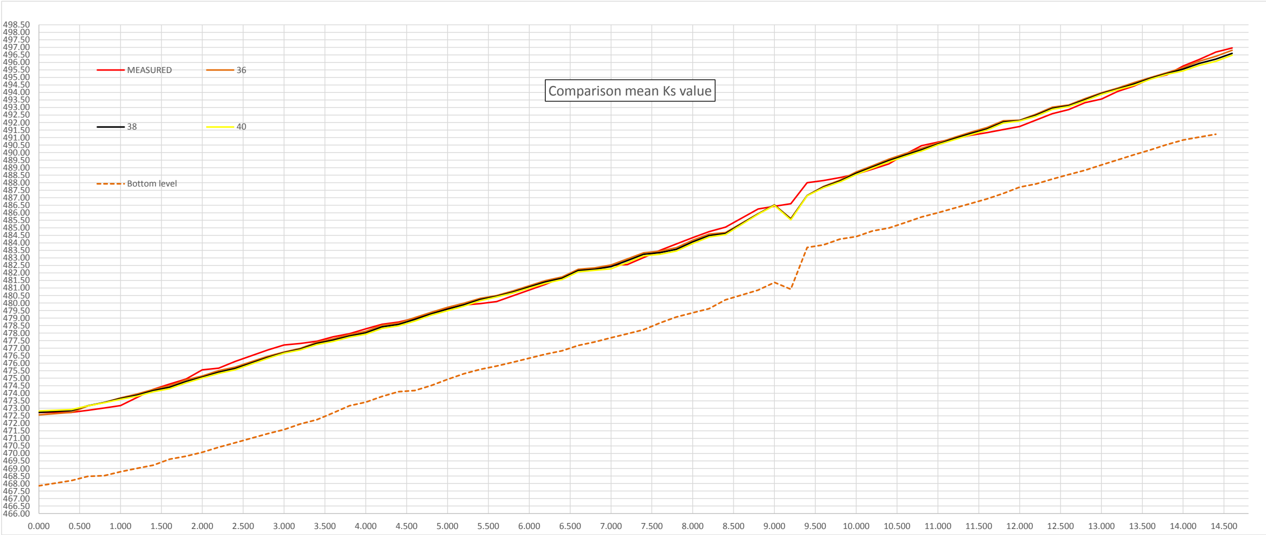


Figure 14: Comparison mean Ks value

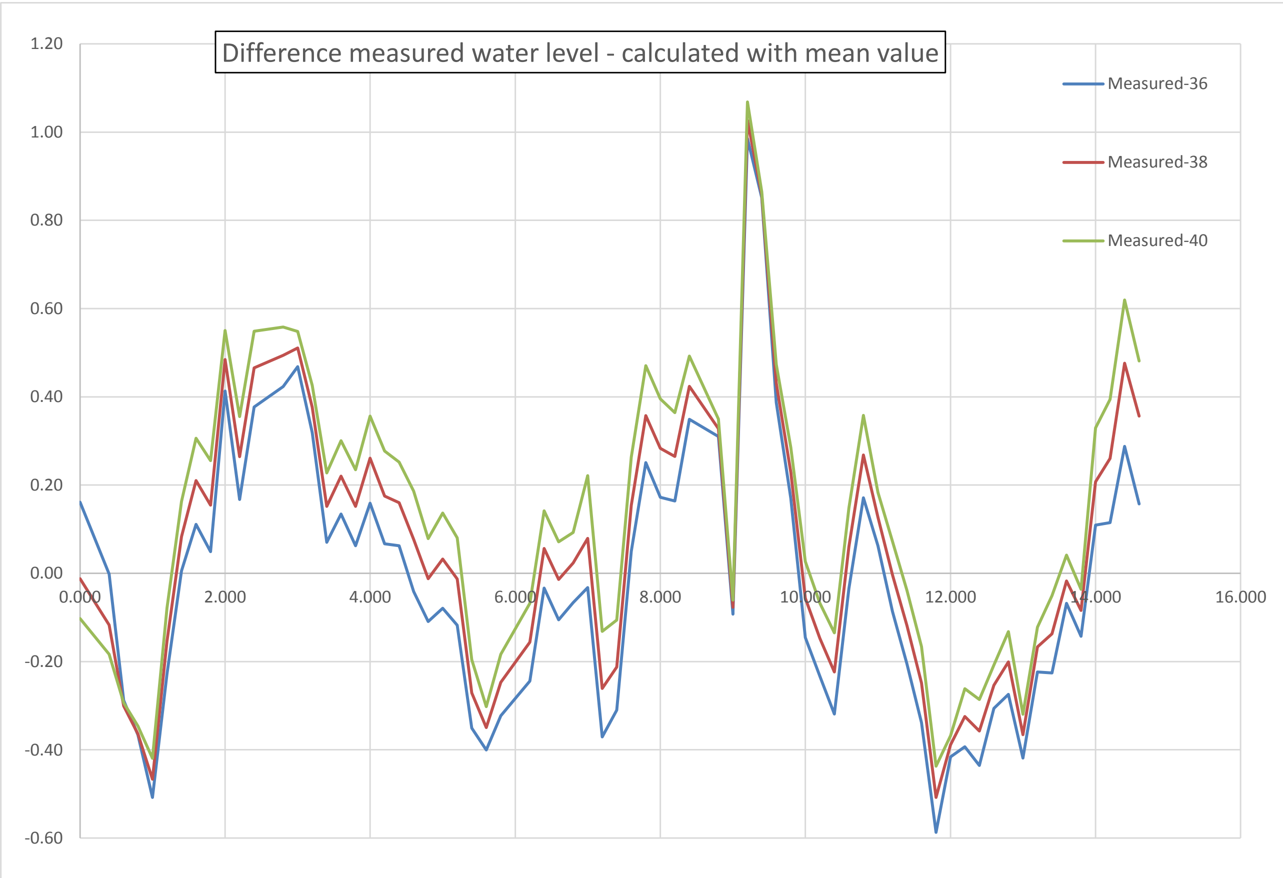


Figure 15: Difference between measured level and calculated one.

The Figure 15: Difference between measured level and calculated one.**Errore. L'origine riferimento non è stata trovata.** shows also the difference between the real measurement and the simulated one: the best value results 38 $m^{1/3}/s$.

Once decided the general value of the friction coefficient that best trace the real water surface level, the cross section showing big difference are singularly modified in the geometry file till the simulated model reproduce the real one with a percent of error lower as 10 cm.

The modification of single element is made appointing not only unique Ks value in the entire cross section, but in many cases it is also necessary distinguish the value of the river bed from the bank of the river. Therefore, the element are divided into three ranges: the central one represent the bottom level of the river, the other two the bank which I fixed with the same value of Ks. A good way to use this different value of friction in the same section is to support the central flow: increasing the friction value of the river sole and at the same time lowering those of the cliffs the water can flows faster and the water level registered should be lower.

The **Errore. L'origine riferimento non è stata trovata.** shows the final Ks assignation and the difference of the water level surface in *Figure 17: Difference real water level(may,1999)/ calibrated.*: most of the points present difference in the order of few centimeter. In some sections is difficult to reproduce the same level appointing a reasonable value of Ks because are present some important difference of level produced from external element like the bridges and weir, as previously said. So in that the section we can see where the differences are smaller than +/- 10 cm from the real water level measured.

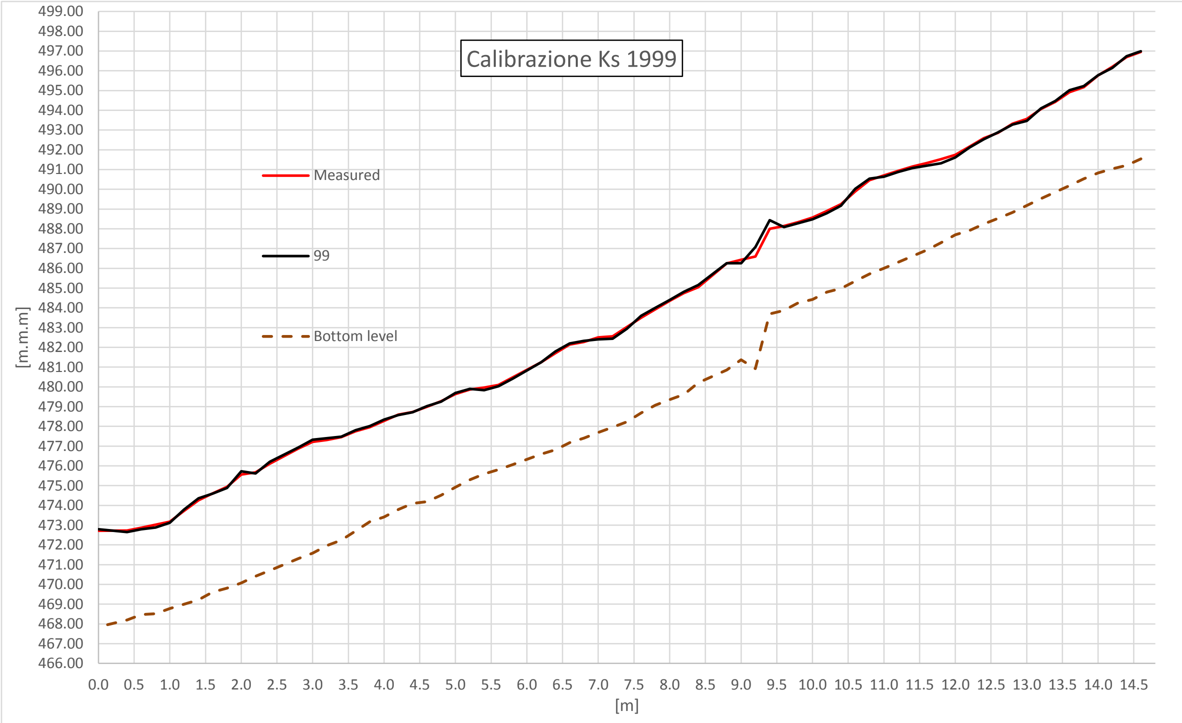


Figure 16: Hydraulic model calibrated, 1999.

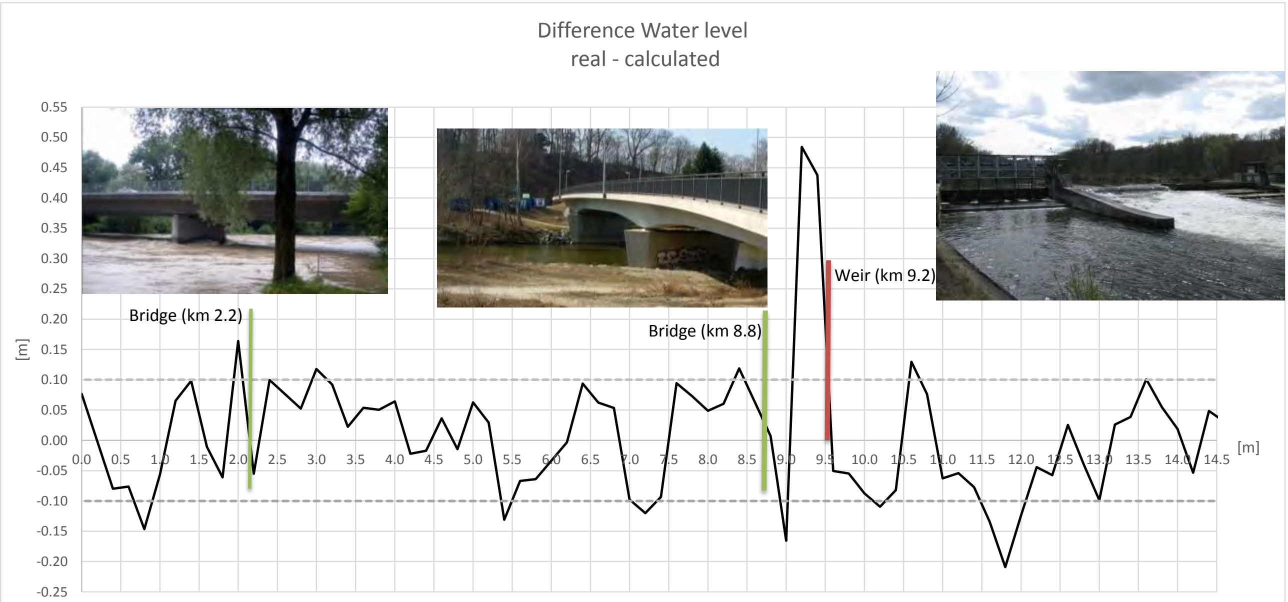


Figure 17: Difference real water level(may,1999)/ calibrated.

5.1.2.2 2005

The measured data for the creation of the geometry file of this project refer to August 2005. The discharge taken is the average value of the real registered data of that month: 120,26 m^3/s.

In the 2005 file grid, the section considered end at the km. 9,2. In this case the Ks assignation will be the same of that one made in the previous part and it will be studied the difference of the water surface level. This identity of the Stricker value in different year is essential for the veracity of the model.

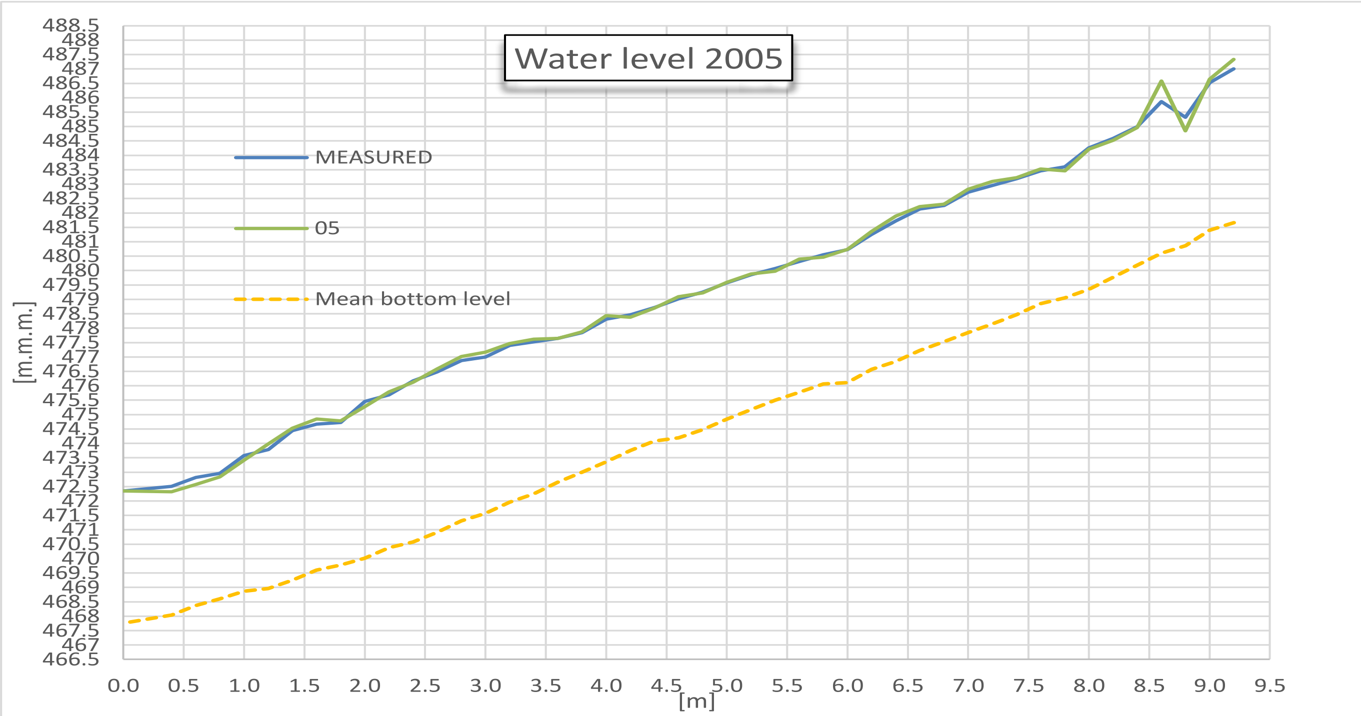


Figure 18: Hydraulic model calibrated, 2005

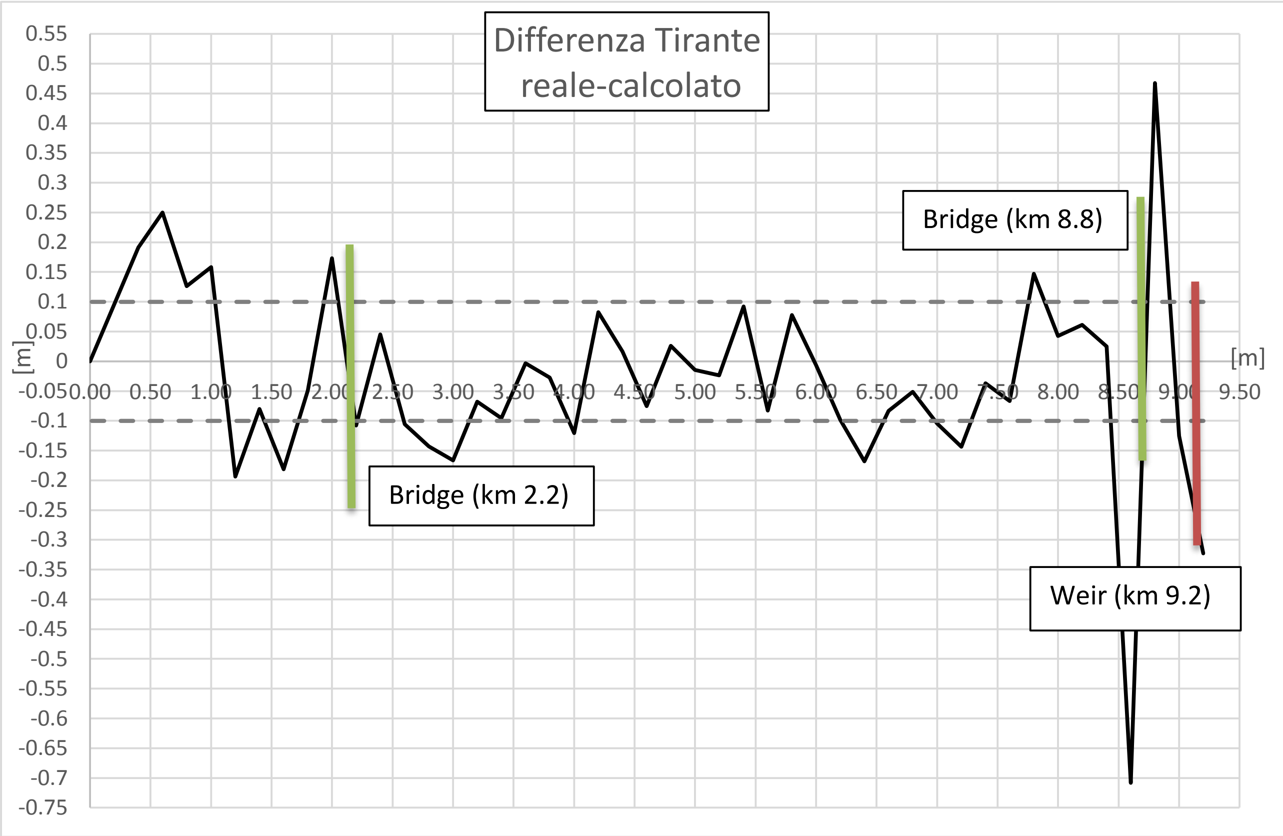


Figure 19: Diffenerence real water level(august,2005)/ calibrated.

Figure 19: Diffenerence real water level(august,2005)/ calibrated. shows the difference between the real level and the measured one. Also in this case there are big difference limited in the near of the structure that cross the river. The complete stretch register values inside the fixed range of +/- 10 cm from the real measurement of the water level. In the last part of the river near the confluence the values are over the limit range but the biggest value is + 25 cm and above all the stretch considered is small if we compare it with the whole length.

In the end the Ks assignment of the model reproduce with good accuracy the hydraulic evolution of the river: the water level modelled well trace the real value measured in 1999 and in 2005 without relevant differences. Once calibrated the hydraulic outline of the model, the following step consist of the morphological calibration.

5.2 Morphological calibration

The morphological calibration is fundamental for the veracity of the model. In this step, the Morphology block will be added in the Edit Command section of Basement. The aim of this work is an investigation of a 1-D model, thus the work will focus on the one dimensional tool and function. This block contains all the information about bed material, grain class assignation and the bed load transportation: if this last block does not exist, then no bed load transport will be simulated. In the following list will be explained the most important tools:

- Parameter: it contains the general settings for 1-D investigation dealing with sediment transport. It contains parameter concerning both bed load and suspended load. The main parameter refers to density and porosity.

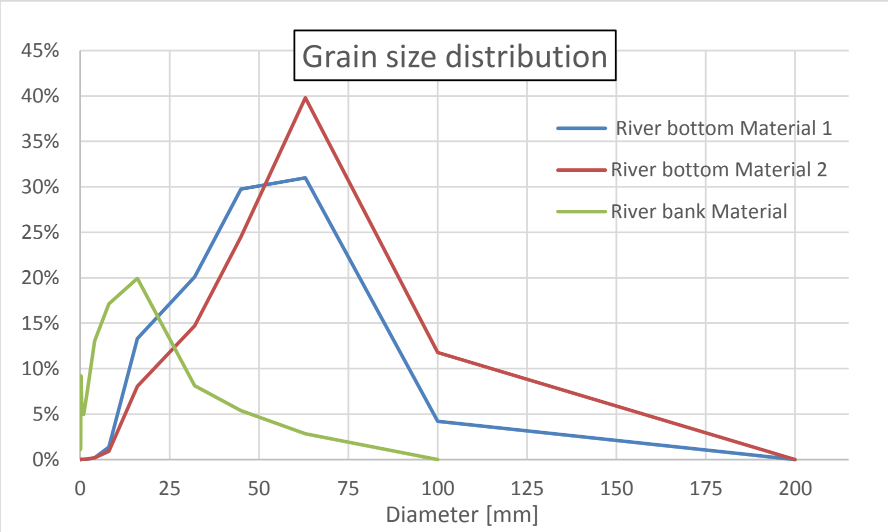
The following two blocks are the most important and contain subdomains:

- Bed material: concern all the data of the bed material. The “Grain_Class” defines the mean diameters of all possibly occourring grains of the bed material in millimeters. The “Mixture” allows producing different grain distribution with the defined dimaters. The “Soil_Def” block defines the sub layers and their mixtures, so that the user can introduce different kind of sediment distribution in the river stretch.

- Bedload: this is the most important block because defines all needed data for bedload transport. “Parameter” subdomain contain the “Bed load_transport” that defines the bedload computation approach to use. The most important apporach available are Meyer-Peter Mueller; Meyer-Peter Mueller Hunziker; Parker; Wu, Wang and Jia. For each formula there are important calibration factor for example: theta_critic, critical_shear_stress, hiding_exponent and bed_load_factor.

The “Boundary” condition define the upper and the lower boundary for the bed load transport.

Measurement of the grain size distribution alongside the Iller are provided and they will be associated with the corresponding area.



Km	Bottom material
0-1	1
1-1,5	2
1,5-2,15	1
2,15-2,65	2
2,65-3,2	2
3,2-4,45	2
4,45-7,55	2
7,55-7,9	2
7,9-16,5	2
16,5-17,6	1

Figure 20: Grain size distribution and material distribution alongside the Iller.

There are two different grain size distribution for the mixture of the river bottom and only one for the river shore.

After this step it will be taken into account the main bed load formula provided by Basement looking for the best one that can trace the mean bottom level of 2005 starting from the geometry grid of 1999. For this reason the main calibration parameter for each approach will be varied and compared. The approach examined are: Meyer-Peter Mueller; Meyer-Peter Mueller Hunziker; Parker; Wu, Wang and Jia.

Before studying each case it will be analyzed the real difference of the mean bottom level between year 1999 and 2005. As already said the geometry information of the 2005 file are limited from km. 0 till km. 9,2 so the information of 1999 that exceed that cross section will be neglected: one of the goal of the morphological study is to build the bed load evolution in the missing stretch (km 9,2 – km 14,6).

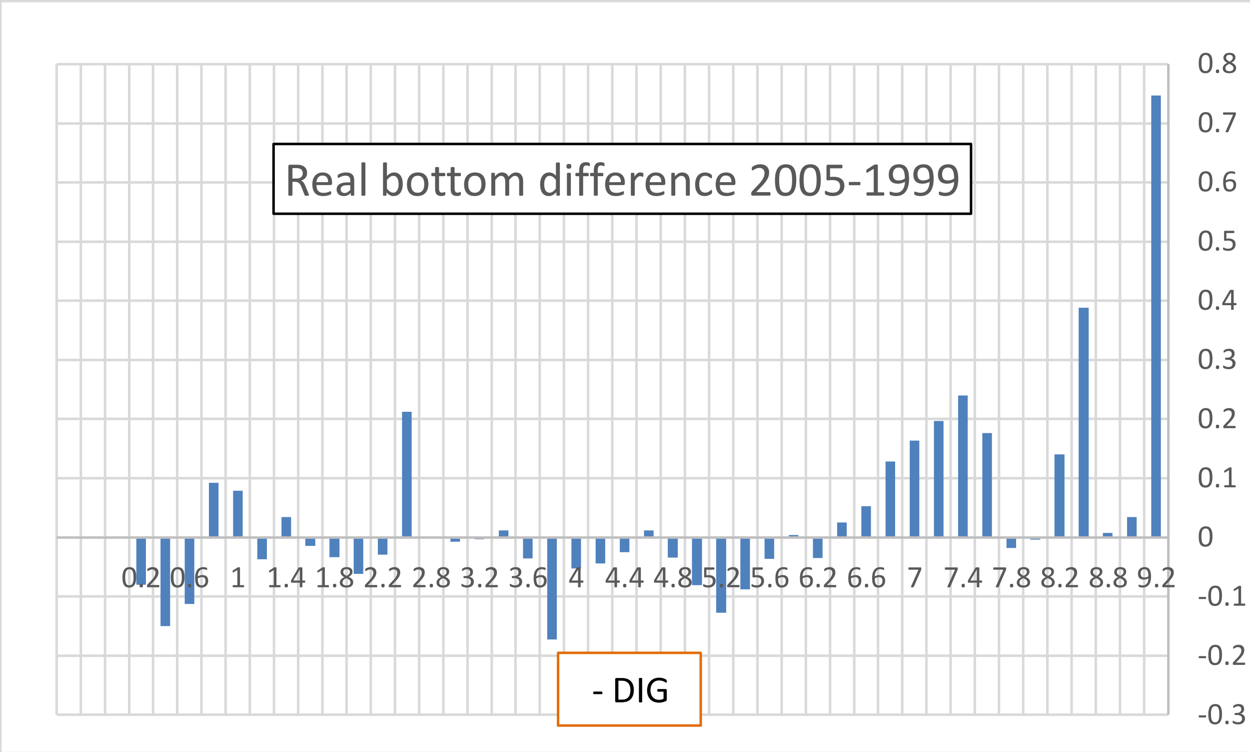


Figure 21: Moprhologic evolution of Iller

Although the hydrograph registered is unsteady and the period of observation is relatively long (six years) it is clear that there is a low level of evolution of the river bottom: there are only few section where the difference between the level of 1999 and 2005 overtake 10 cm and only four that reveal an overtake of 20 cm.

Before observing the results of the four different approach the model is enhanced with the grain size distribution related to the river bottom and shore. Unfortunately, in this phase Basment crashed and did not allow to calculate any domain. The model runned with only one grain distribution of the river bottom and shore. Since the river bottom material 2 interest the larger part of the stretch and since the grain size distribution between that and the bottom material 1 is not so different, it will be decided to take into account only one distribution alongside the river coinciding with the material 2.

Now it will follow the description of the different approach results, changing also the parameter that most influence each approach itself. The following bed load transport formulas calculate the transport capacity of the most important bed load transport formula provided by Basement: Meyer-Peter Mueller; Meyer-Peter Mueller Hunziker; Parker; Wu, Wang and Jia.

5.2.1 Closures for Bed Load Transport

In the following a variety of bed load transport formulas are listed which are implemented to calculate the transport capacity. For practical purposes usually a calibration of the used formula is needed and several parameters can be adjusted by the user.

In the following analysis the main calibration factor object of study are:

- Critical shear stress: Factor used to modify the critical shear stress returned by the Shields diagram. It can only be used for transport formulas which determine the critical shear stress from the Shields-diagram.
- Bed load factor: This factor is multiplied with the bedload transport computed by the bedload approach and can be used as a calibration parameter.
- Hiding: Factor of the exponent of the hiding-and-exposure function in Hunziker's or Wu's fractional bed load formula. Changing this exponent primarily has influences on the grain sorting processes.
- Theta critic: this factor have an effect on the Shields diagram;

5.2.1.1 Meyer-Peter and Müller (MPM & MPM-Multi)

The formula of Meyer-Peter and Müller (Meyer-Peter and Müller 1948) can be written as follows:

$$q_{Bg} = \left(\frac{\tau_{B-}\tau_{B_{cr,g}}}{0.25\rho}\right)^{3/2}\left(\frac{1}{(s-1)g}\right)$$

Herein, τ_B is the effective shear stress induced by the flow; $\tau_{B,cr}$ is the critical shear stress for each grain size class g. and s= ρ_s/ρ the sediment density coefficient. In the dimensionless shape the formula can be written as:

$$q_{Bg} = \phi_B \sqrt{(s-1)g} {d_m}^{3/2}$$

with

$$\phi_B = 8(\theta' - \theta_{cr})^{3/2}$$

Meyer-Peter and Müller observed in their experiments that fist grains moved already for $\theta_{cr} = 0.03$. But as their experiments took place with steady conditions they used a value for which already 50% of the grains where moving. They proposed the value of 0.047. However for very unsteady conditions one should use values for which the grains really start to move like the values given by the shields diagram. (Wieprecht, 20.11.2013)

The formula of Meyer-Peter and Müller is applicable in particular for coarse sand and gravel with grain diameters above 1 mm. This bed load formula is only applicable for single grain simulations. But an extension of the MPM-Formula for fractional transport is implemented in the program and called MPM-Multi. It uses a correction factor ξ_g for the incipient motion. The dimensionless critical shear stress of grain class becomes: $\theta_{cr} = \xi_g 0.047$.

5.2.1.1.1 Iller Mpm_multi calibration

The parameter object of study are: critical shear stress and bed load factor. As well as those two parameter at first time it is studied the morphological development of the formula without modifying any variable (nullvariante). The model starts from 1999 with the real hydrograph as input and ends in 2005. The single resultst will then compared with the real measurement of 2005.

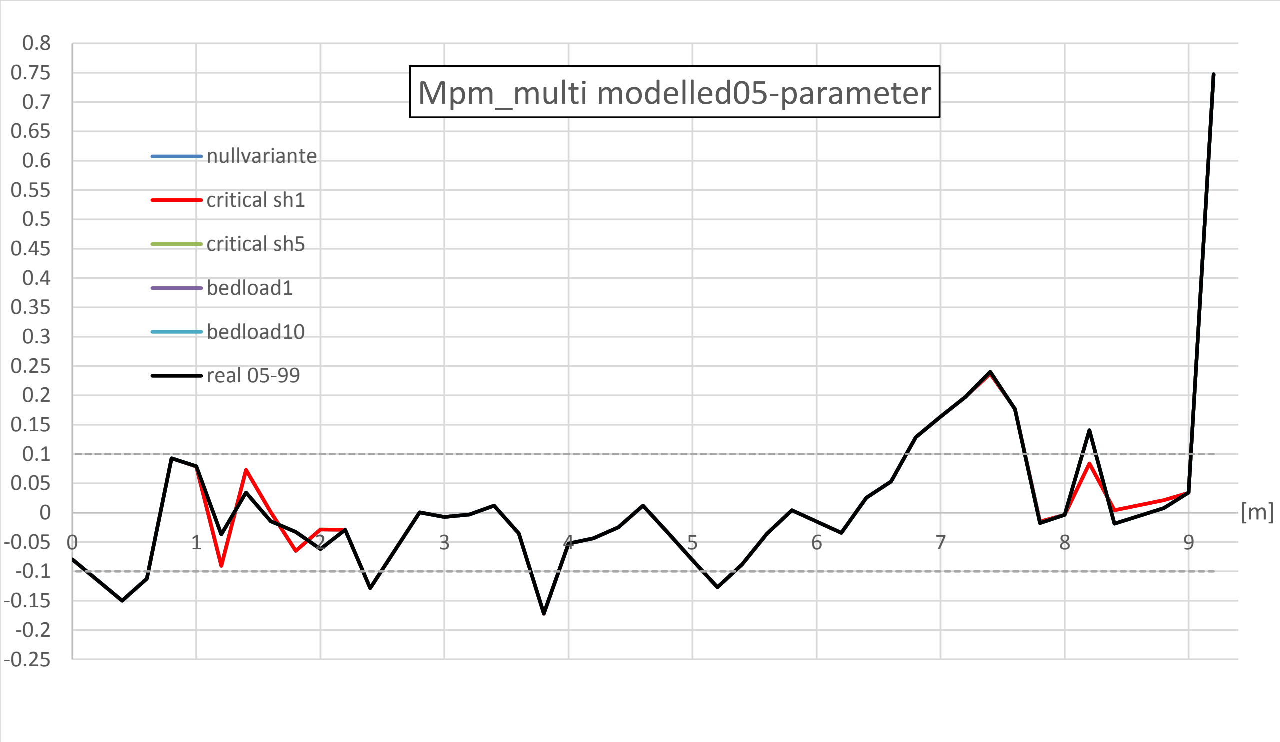


Figure 22: Mean bottom level difference Mpm_multi.

As we can see this model present no bed load transportation: the mean bottom river of the 2005 modelled does not show any change in the different parameter variation. Only the critical shear stress show difference of the river bottom but they are limited only in a small range and above all, the trend of the bottom evolution diverge from the measurement of 2005.

5.2.1.2 Hunziker (MPM-H)

To map transport processes of mixed sediments and to calculate according bed load discharge, corrections or special formulas for graded sediments have to be applied. Besides the ability to model grain sorting in the active layer, the exposure of bigger grains to the flow and the involved shielding of fine sediments, the so called hiding effect has to be considered. A special formula for the fractional transport of graded sediments was proposed by (Hunziker 1995):

$$q_{Bg} = 5\beta_g\left[\xi_g(\theta'_{dms} - \theta_{cdms})\right]^{3/2}\sqrt{(s-1)gd_{ms}^3}$$

The additional shear stress $(\theta'_{dms} - \theta_{cdms})$, regarding the mean grain size of the bed surface material, is corrected by a corresponding hiding factor.

Due to the correction of the additional shear stress $\theta'_{dms} - \theta_{cdms}$, the transport formula bases on the concept of "equal mobility", i.e. all grain classes start to move at the same flow conditions. The critical Shields value is calculated with the mean grain diameters and is given by:

$$\theta_{cdms} = \theta_{ce}\left(\frac{\mathrm{d}_{mo}}{\mathrm{d}_{ms}}\right)^{0.33}$$

Where θ_{ce} = critical shear stress for incipient motion for uniform bed material. Hunziker's formula distinguishes thereby between two sediment layers, the upper layer which is in interaction with the flow and an underneath sublayer. Here d_{ms} is the mean diameter of the upper layer and d_{mo} is the mean diameter of subsurface bed material.

The hiding factor is determined as:

$$\xi_g = \left(\frac{\mathrm{d}_g}{\mathrm{d}_{ms}}\right)^{-\alpha}$$

where α is an empirical parameter which depends on the dimensionless shear stress of the mixture. The parameter α is determined as:

$$\alpha = 0.011\theta'^{-1.5} - 0.3$$

5.2.1.2.1 Iller Hunziker (MPM-H) calibration

In this case relevant calibration factor results: hiding exposure, critical shear stress and bed load factor.

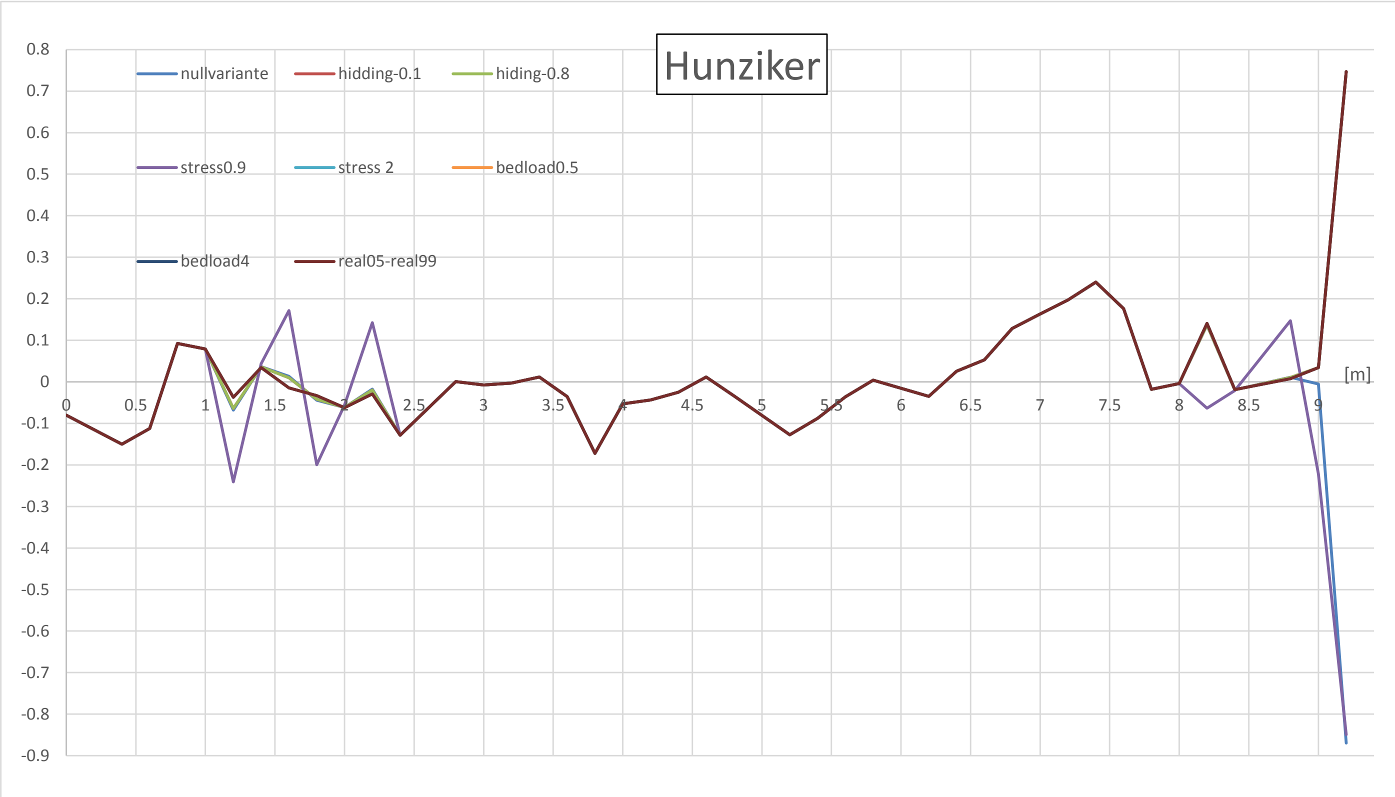


Figure 23: Mean bottom level difference Mpm-hi.

Also in this model there are parameter that does not influence the morphological evolution of the river bottom, showing no difference with the model of 1999. Those that show an increasing of the mean bottom transport are the Shear stress and hiding factor: the first one produce great difference but the trend is divergent; the second one has a small change and the trend is also divergent from the calucated section. All the model in the central stretch of the river show no sediment movimentation tracing the same bottom profile of the 1999.

5.2.1.3 Parker

Parker (1990) has extended his empirical substrate-based bed load relation for gravel mixtures, which was developed solely with reference to field data and suitable for near equilibrium mobile bed conditions, into a surfaced-based relation. The new relation is proper for the non-equilibrium processes.

Based on the fact that the rough equality of bed load and substrate size distribution is attained by means of selective transport of surface material and the surface material is the source for bed load, Parker has developed the new relation based on the surface material. An important assumption in deriving the new relation is suspension cut-off size. Parker supposes that during flow conditions at which significant amounts of gravel are moved, it is commonly (but not universally) found that the sand moves essentially in suspension (1 to 6 mm). There for Parker has excluded sand from his analysis.

$$W_{si}^{*} = 0.00218\, G[\xi_s \omega \phi_{50}]$$

Where the reduced hiding function is $\xi_s = \left(\frac{d_i}{d_g}\right)^{-0.0951}$; $\phi_{50} = \frac{\tau_{sg}}{\tau_{50}}$ and $\tau_{sg} = \frac{\tau_B}{\rho R g d_g}$, $\tau_{50} = 0.0386$

Regarding to the fact that parker's relation is based on field data, the relation calculates low bed load rates.

5.2.1.3.1 Illler Parker

The only parameter considered is theta critic: it is usually gathered from the Shields diagram. As we can see in the following

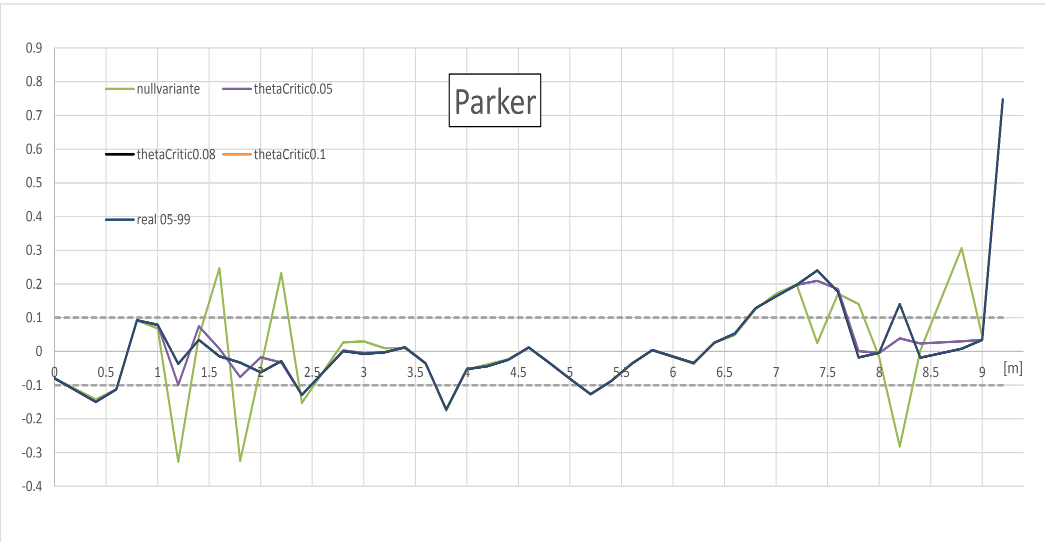


Figure 24: Mean bottom level difference the model produce bottom level changes relevant compared to the other two models just

analyzed. The “nullvariante” also yield to high transport although the trend is divergent. The “theta critic 0.05” has a good trend but is limited to a strict number of section.

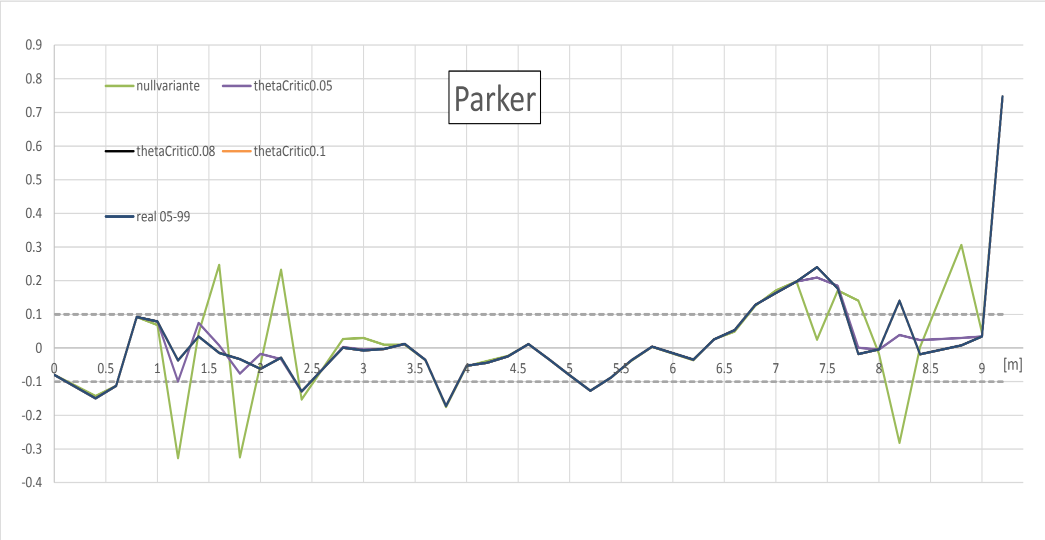


Figure 24: Mean bottom level difference Parker.

5.2.1.4 Wu Wang and Jia

Weiming Wu, Sam S.Y. Wang and Yafei Jia (2000) developed a transport formula for graded bed materials based on a new approach for the hiding and exposure mechanism of nonuniform transport. The hiding and exposure factor is assumed to be a function of the hidden and exposed probabilities, which are stochastically related to the size and gradation of bed materials. Based on this concept, formulas to calculate the critical shear stress of incipient motion and the fractional bed-load transport have been established. Different laboratory and field data sets were used for these derivations.

The probabilities of grains d_g hidden and exposed by grains d_i is obtained from: $p_{hid\ g} = \sum_{i=1}^{ng} \beta_i \frac{d_i}{d_g + d_i}$ and $p_{\exp g} = \sum_{i=1}^{ng} \beta_i \frac{d_g}{d_g + d_i}$.

The critical dimensionless shields parameter for each grain class g can be calculated with the hiding and exposure factor η_g and the shields parameter of the mean grain size $\theta_{cr\ m}$ as:

$$\theta_{crg} = \theta_{cr\,m}\,\eta_g = \theta_{cr\,m}\left(\frac{p_{\exp g}}{p_{hid\,g}}\right)^m$$

The transport capacity now can be determined with Wu's formula in dimensionless form as:

$$\phi_{Bg} = 0.0053\left(\frac{\theta'}{\theta_{crg}} - 1\right)^{2.2}$$

Finally the bed load transport rates calculates for each grain fraction as:

$$q_{Bg} = \phi_{Bg}\sqrt{(s-1)g}\,{d_m}^{3/2}\beta_g$$

Since this critical dimensionless shear stress is in the denominator of the transport formula, such situations may lead to numerical instabilities. To avoid these problems a minimum value for θ_{crg} is enforced: θ_{crg}= min($\theta_{crg,min}$, θ_{crg}).

5.2.1.4.1 Iller Wu calibration

In this last instance the parameter analyzed are: theta critic, hiding exopistion factor and critical shear stress. This formula well suit the river bottom transportation and we can see that the graph corresponding of the different parameter deviate from the value of 1999.

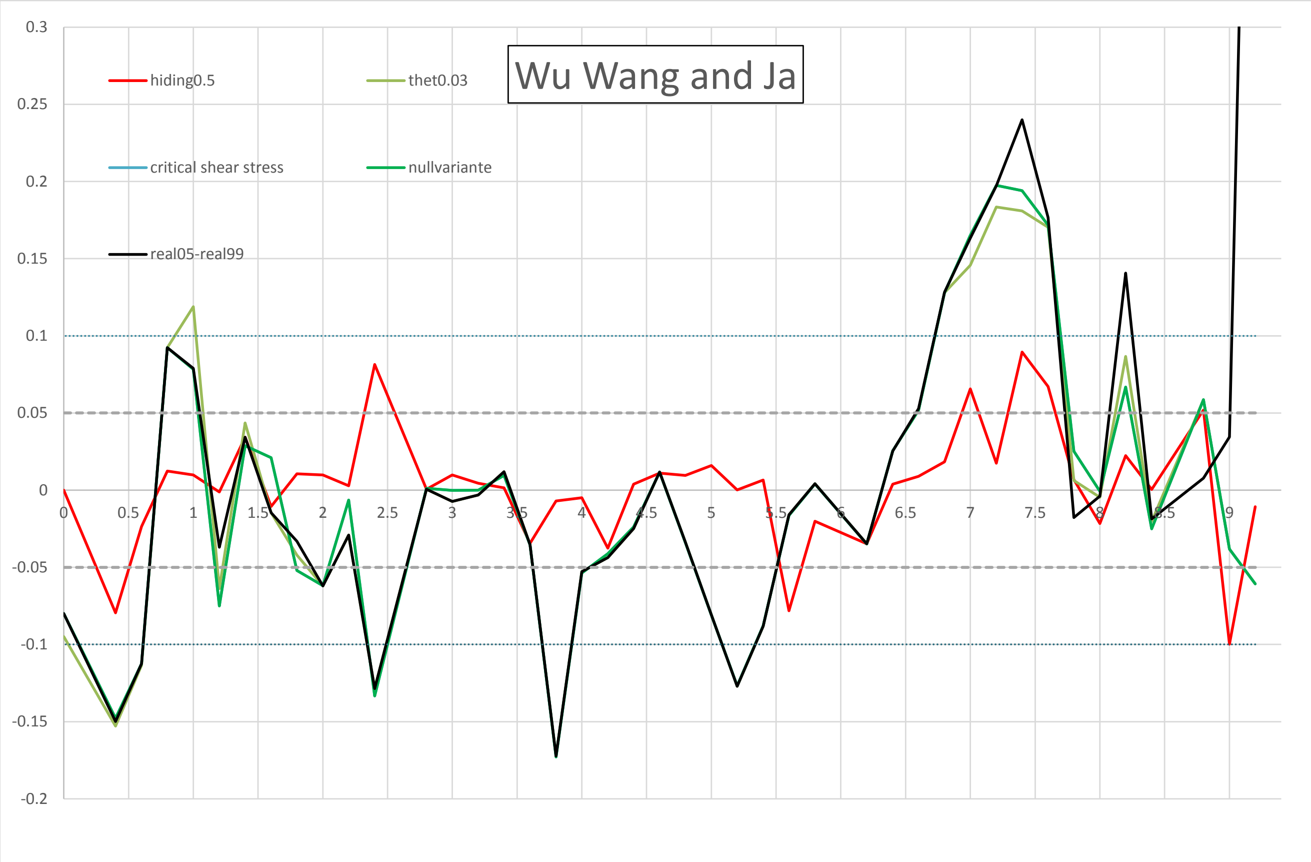


Figure 25:Mean bottom level difference Parker.

Even though nullvariante and the theta critic parameter discern from the 1999 measurement their trend is in some stretch too much over the range of acceptability. Instead, the hiding factor get close the 2005 value and above all differs in most of the segment less than +/- 5cm. Another important element of analysis is the general trend of the model to reproduce the dig or deposit during the runtime period. As we can see in the following Fig. the hiding curve reproduce with a good accuracy the dig and deposition alongside the stretch and there is a difference, negligible in value, only in the segment from km 6.4 till km 5.4.

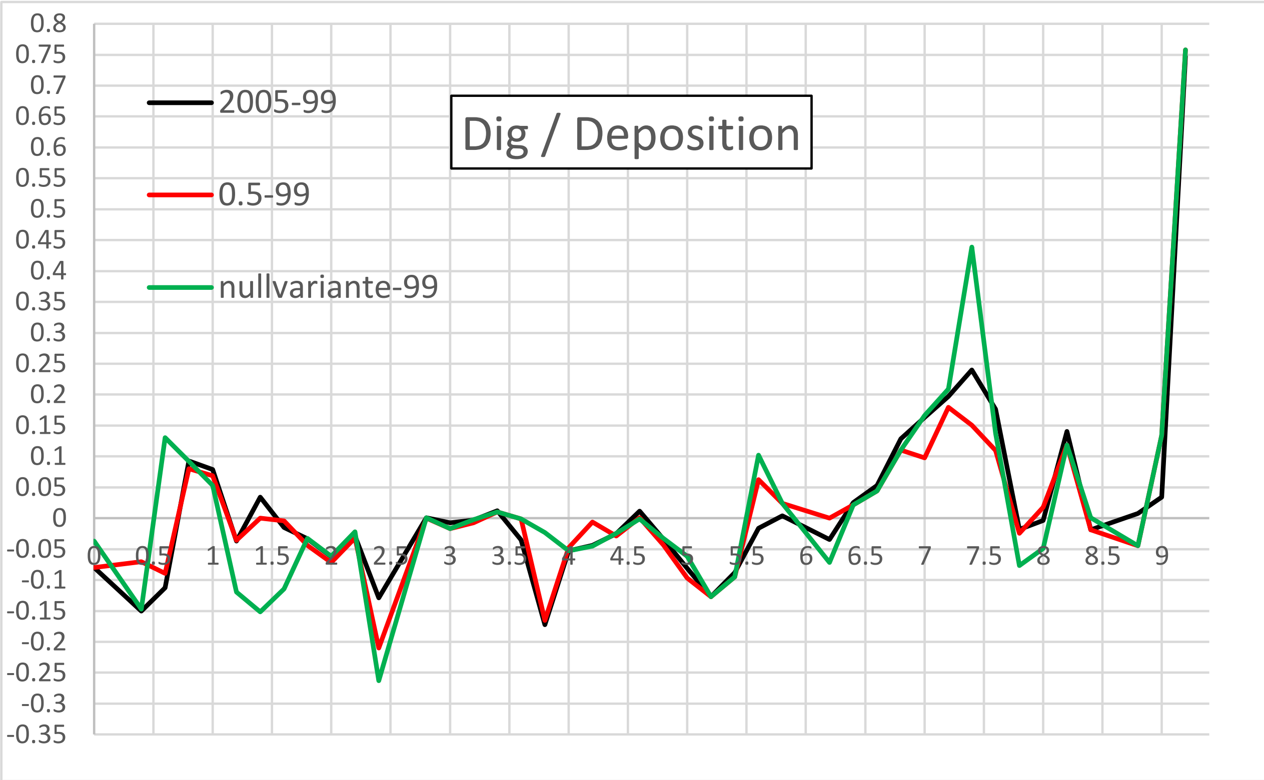


Figure 26:Real Erosion/deposition trend compared with the modelled one (Wu)

5.3 Calibrated model

Comparing the best results for each formula, the Wu Wang and Ja approach indicate the best morphology evolution of the model because it reproduces not only the nearest value of the real mean bottom Iller of 2005, but also it follows the real trend of dig and deposition alongside the river. Whithin the paramters of the Wu formula that show the biggest inclination to the sediment transport, the hiding exponent results the most valuable calibration factor also because the approach focus on the development of that factor.

Another important goal of this part of the work is to discover how the upper part of the Iller (from km 9.2 till km 14.4) develops in sense of sediment dig and deposit: since the model is calibrated it should approximate ostensibly the trend. The weight of sediment transportation is contained into a limited range in the order of +/- 10 cm as it is registered in the real difference of the bottom level concerning the section from km. 0 till km.9.2.

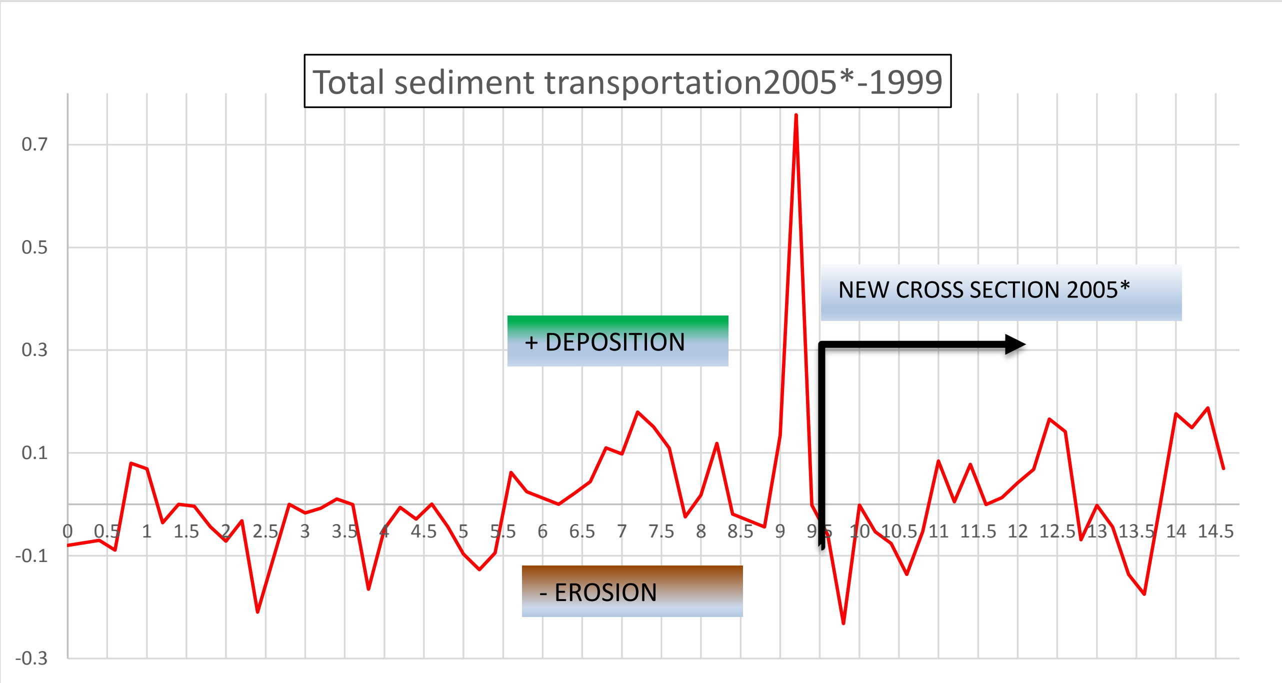


Figure 27: mean bottom difference 1999-2005 calibrated with Wu.*

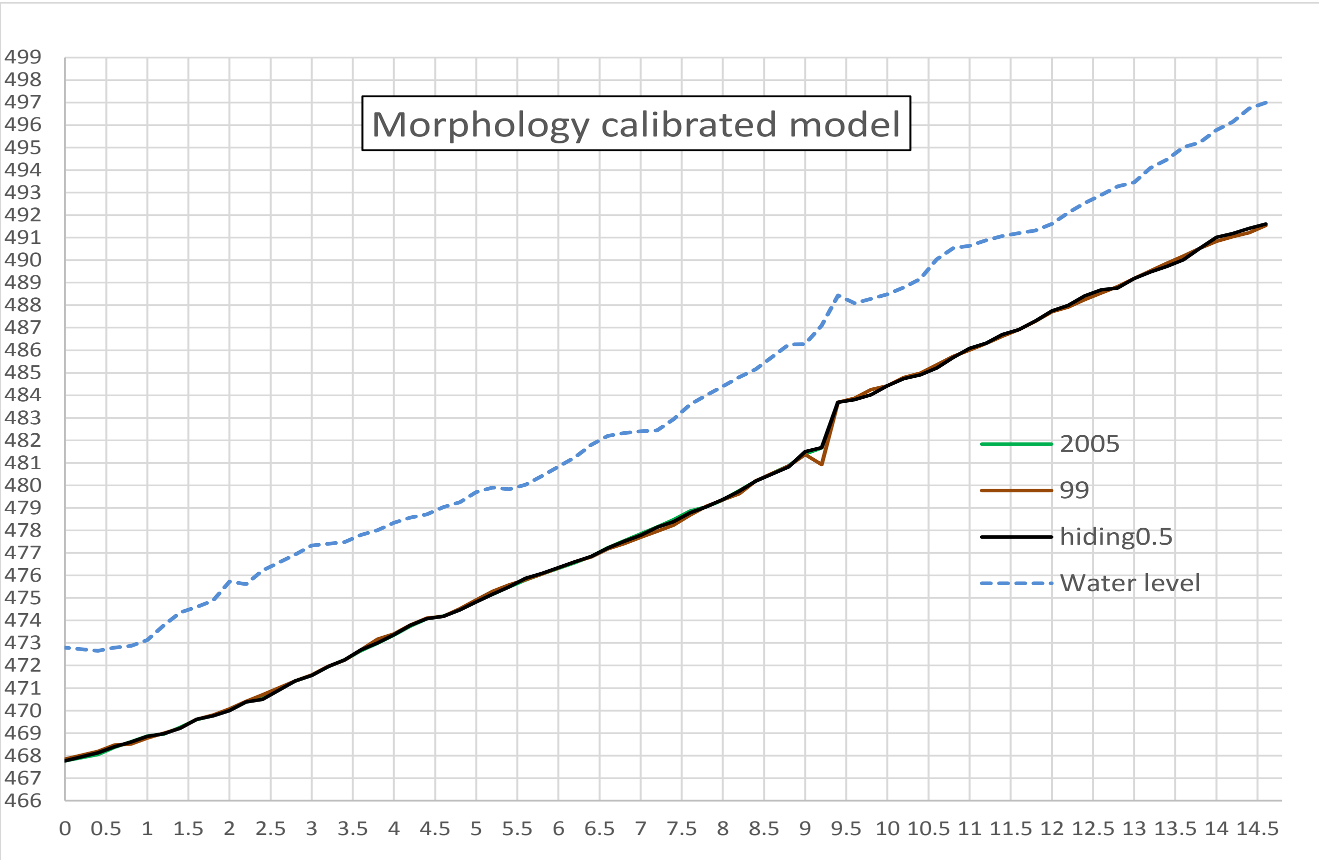


Figure 28: final model morphologically calibrated (Wu).

6 Hydrological adaption

Once having calibrated the model, the final goal of this work is looking for the value of continuous discharge that allow to create the same level of deposition and dig alongside the river domain.

The work focus on the input file where the discharge will not represent the real hydrograph of Iller but a constant value that does not change in the six years of simulation.

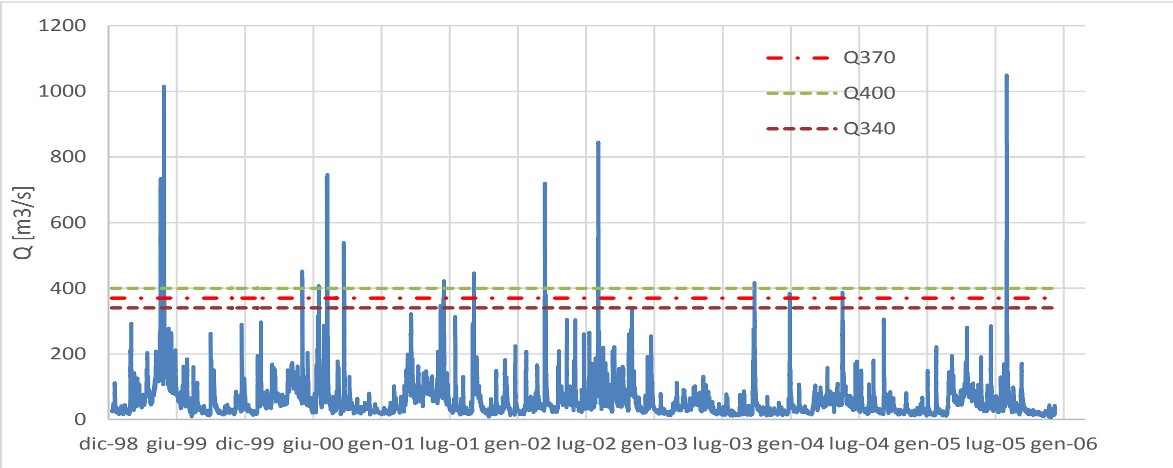
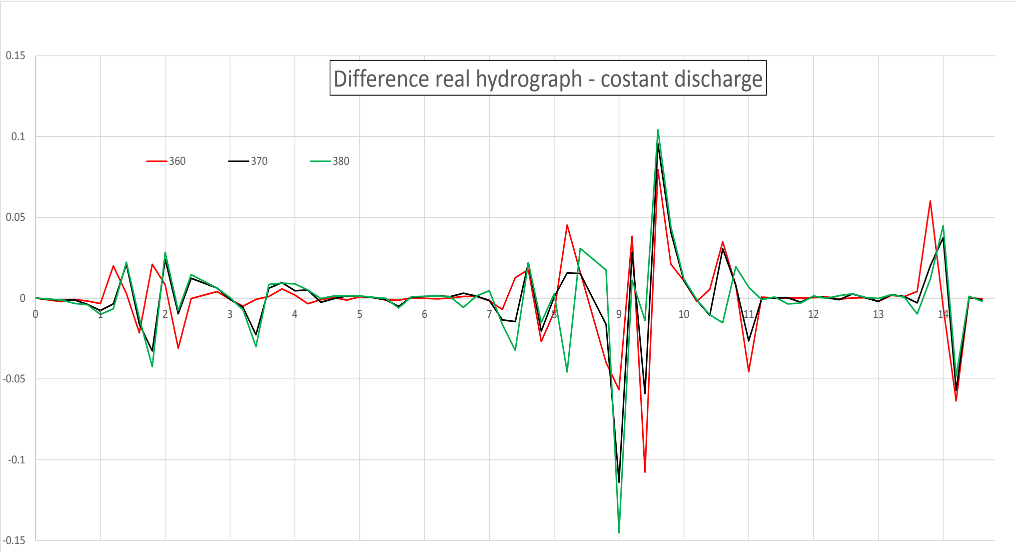


Figure 29: Real Iller Hydrograph.

The following Figure 30: differences model with real hydrograph and with contiunous discharge. compare the differences between the mean bottom level of the Iller calculated with the real hydrograph and that one modelled with the continuous discharge. The results of discharge with 360 m^3/s and 370 m^3/s are clos-set: they are both included inside the range of +/- 5 cm of difference from the real. An analysis of the difference for the value that overtake 5cm and 2.5cm reveal that the most accurate one is the hydrograph build with Q=370 m^3/s, as it is possible to see in the following figure.



	Q360	Q370
	Δ>5cm	Δ>2.5
14.2	-0.06356	-0.05695
13.8	0.06018	0.01994
11	-0.04546	-0.02647
10.6	0.0349	0.03057
9.8	0.02105	0.04081
9.6	0.0796	0.09554
9.4	-0.10763	-0.05895
9.2	0.03833	0.02811
9	-0.05675	-0.11386
8.8	-0.03987	-0.01625
8.2	0.04526	0.01562
7.8	-0.02689	-0.0205
2.2	-0.03102	-0.00962
1.8	0.02094	-0.03269
1.6	-0.02145	-0.01601

Figure 30: differences model with real hydrograph and with contiunous discharge.

7 Conclusion

The morphological investigation has become a problem of great importance in the last years. The river and its natural evolution has been modified by human activity and nowadays almost all the river are in some way altered from their natural behavior. The comprehension of the consequences of the engineering measures alongside a river could allow to understand for each case the effects of them, in particular on the sediment transport. Indeed the construction as dam, gate and weir prevent the grain size of bigger dimension their natural flow alterating it. The work is made to examine the Iller hydro-morphological evolution and to create a model able to reproduce it.

Basment is the software, developed by the Eth university, that was exploited for a one dimensional study: throughout the work it was possible to see the limit of the program but also the bright side.

The work started with the pre-processing phase that consist of transport the real data for example the geometry of the river and the topographical data to the software to create the mesh grid.

Then the model must be calibrated: both hydrologically and morphologically. The calibration section is characterized by the variation of the most important parameter acting in the process.

In the hydrological fraction the difference between the water level modelled and real measure on the field should register a confidence interval with a range of +/-10cm. Even though the work focus on the morphological evolution the parameter assignation did not satisfy at all the range given, and above all it was impossible to reproduce a water level with more accuracy.

The Morphological fraction, more important for the final goal of the thesis, should complete the creation of a plausible model appointing the grain size distribution in the different stretch measured alongside of the river. Here Basement showed its limit because the program continue to crash during the iteration process and it was allowed only one size distribution without showing this kind of problem. Fortunately, the two grain size distribution of the river bottom registered did not show any important difference and with an approximation the model proceed.

The main bed load formula proposed by the program was studied running the program for 6 years with the aim to find an interval of confidence of +/-10 cm of the mean bottom level difference. In this case it was found the Wu Wang and Ja, modifying the Hiding factor parameter of the formula, well trace the corresponding real profile of 2005 with a confidence interval of +/- 5 cm.

The last part of the work look for finding a continuous discharge that can reproduce the same sediment transportation changing in this way the input file previous made by a real discharge hydrograph. In this last test the discharge that best trace the mean bottom level of 2005 is Q=370 m^3/s and the accuracy of the confidence interval is +/-2.5 cm with only few value of the cross section that exceed the range.

At the end, although the program show some lack in the hydrological calibration the following morphological calibration well reproduce the sediment transport of the river Iller. The model created in this way is useful to analyze stretch of Iller and predict the evolution of the river in case of engineer measurement.

Bibliography:

Ethz University: (2013). Refenece Manual of Basement.

Ethz University: (2013). *System Manual of BASEMENT.*

Papanicolaou, A. N. (2008). Sediment Transport Modeling Review—Current and Future Developments.

Wang. (2004). *State of the art River sedimentation and morphology modelling.*

Wieprecht, P. D.-I. (20.11.2013). Bericht Nr. 10/2013 Morphologische Studie Untere Iller (Fkm 56,725 – Mündung) Phase 1.

Wu, W. (2007). *Computational river dynamics.* Taylor & Francis e-Library.

Wu, W. (October, 2004). Computational river dynamics. *Proceedings of the Ninth International Symposium on River Sedimentation.* Yichang, China.